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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

APRIL 2023

Get Ready for the 2024 Total Eclipse

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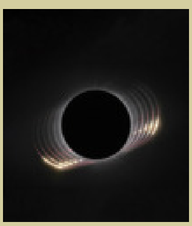
THE ESSENTIAL GUIDE TO ASTRONOMY

April 2023 VOL. 145, NO. 4

NASA / SOFIA SCIENCE TEAM / Y. SEO / ESO

ON THE COVER



Composite image of the July 2019 eclipse, seen from Chile

PHOTO: PETR HORÁLEK

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A Tangible Darkness

WHEN WE THINK *total solar eclipse*, our first thought might well be of the spectacular light effects — of the Sun's ethereal corona or Baily's Beads. But as anyone who has experienced totality knows, the dark effects can be equally thrilling. Up there, it's all about radiance; down here, it's all about shadow.

As totality approaches, you begin to see the western sky darken — the umbral manifestations have begun. (*Umbra* comes from the Latin for shade.) Within minutes of total eclipse, the darkness in the west begins to resemble an approaching thunderstorm. If you're fortunate enough to be on high ground, you can watch the Moon's shadow race toward you across lower elevations. In her 1894 book *Total Eclipses of the Sun*, Mabel Loomis Todd lyrically describes this rapidly ballooning specter as "a tangible darkness advancing almost like a wall, swift as imagination, silent as doom."

▲ The Moon in shadow during the 2017 total solar eclipse

NASA / AUBREY GEMIGNANI

Meanwhile, the light around you has begun to dim and take on a surreal, slate-gray tint. As the crescent Sun thins, its light throws ever-sharper shadows on the ground. If you're near a white building or other suitable surface, you might also detect one of an eclipse's more fleeting phenomena: shadow bands. Resembling sunlight rippling on the bottom of a swimming pool, the undulating bands appear briefly just before and just after totality.

Not surprisingly, the most obvious shadowing effects occur during totality, when the Moon completely blocks the Sun. The landscape dips into twilight. It might be mid-day for you, but it feels like dusk. The temperature drops precipitately, baffled birds head to roost, and crickets start to chirp. Glancing up at the now-hidden Sun, you see the ultimate shadow: the face of the Moon. It appears black as coal, and its temporary vanquishing of sunlight has brought nearby bright stars and planets into view.

Dedicated eclipse chasers, or *umbraphiles*, might have a certain feature of total eclipses that they most look forward to. For many it's the supernally beautiful corona with its lustrous, mother-of-pearl streamers. Others might favor red-tinged prominences or hope to see shadow bands for the first time.

But all would likely agree that what makes a total solar eclipse "the most stunning and awe-inspiring naked-eye event in all astronomy" — as Fred Espenak and Jay Anderson write in their cover story on page 26 — is the full package of light and dark effects. (See them also in Bob King's column on page 48 and Sean Walker's photo essay on page 60.) The synergy can leave viewers in tears.

In one year's time, on April 8, 2024, the second total solar eclipse to cross the U.S. in seven years will transpire. Are your plans in place?

Peter

Editor in Chief

Editorial Correspondence
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NEW
Less Can Be More !
Strain Wave Drive Mounts
This year is shaping up to be iOptron's most innovative yet! In 2022 we stepped on to the strain wave drive stage by introducing the highly anticipated HEM27 and HEM27EC. These two models provided a window into the freedom found through a drive system that doesn't rely on a balanced payload to function. With no cumbersome counter-weights or shafts, these mounts ushered in a new level of portability. This year iOptron will be expanding our strain wave driven products into 3 groups of mounts.
HEM: Consisting of three payload capacities - 15lb, 27lb, and 44lb - HEM versions are available as standard or with EC precision encoders.
HAZ: A new GoTo alt-az mount design utilizing strain wave drive technology on both axes. Two models, one with a 31lb the other a 46lb payload capacity, each featuring our easy set-up "level and go" system. Perfect for satellite tracking, supporting binoculars, or visual observing.
HAE: Offering both equatorial and alt-az modes, this dual-axis strain wave drive mount can do it all. The HAE will be available as a 29lb or 43lb payload capacity model, with or without optional EC (precision encoder).
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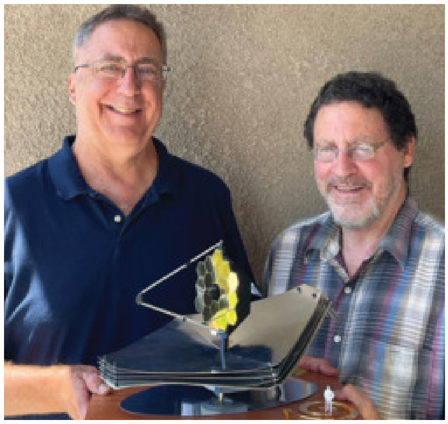
A Model of Brotherly Love

Teaching Astronomy 101 at Mt. San Jacinto College in Southern California has taught me that students enjoy viewing astronomical instruments in 3D. I have commissioned my brother Robert, a retired aerospace engineer from Hughes Aircraft Company, to build several scale models of historic telescopes for my classroom. The latest is a retractable 1/50 scale model of the James Webb Space Telescope (JWST). The model took nine months to complete, much shorter than the roughly 25 years it took to complete the actual telescope.

Robert obtained full-size plans for the telescope from *SketchUp*. Using the same software, he then resized the plans to a scale of 50:1. Next, Robert modeled the 14 unfolding deployment steps in *SOLIDWORKS* to obtain the correctly sized plans for each individual moving part. The model's 14 deployments were achieved using 21 magnets and 30 springs.

Pololu Corporation, a machinery company headquartered in Las Vegas, Nevada, laser cut the primary mirror, spiral label, and silicone elastic bands based off the *SOLIDWORKS* plans. The primary mirror was constructed from gold reflective styrene. Making the telescoping booms that extend the sunshield proved to be the most difficult part of the project. NASA's JWST website (**jwst.nasa.gov**) was a valuable source of information concerning the layout of the telescope.



▲ Brothers Mark (left) and Robert Maier pose with their foldable model of the James Webb Space Telescope.

When the first pictures from the JWST were just being released (*S&T:* Nov. 2022, p. 12), Robert and I were both astonished by their beauty and detail. I am sure that the students in my Astronomy 101 classes this semester will greatly appreciate being able to see this model firsthand.

Mark Maier
Menifee, California

Roaming Planets

I thought Rebekah Dawson's "Star Huggers" (*S&T:* Oct. 2022, p. 28) did an excellent job of explaining postulated planet-migration mechanisms and how they might be correlated to the observed distribution. The tidal-migration mechanism was primarily cited for its orbit circularizing effect, but little mention was made of progressive orbital shrinkage due to tidal effects when the planet orbits faster than the rotational rate of the star. This effect would seem to be important in that close orbiting planets progressively spiral inward to their destruction.

Lyman J. Petrosky
Latrobe, Pennsylvania

Camille Carlisle replies: *Thanks for your letter. I shared your question with Rebekah Dawson, who replied, "Tides raised on the planet by the star can be important for the hottest of hot Jupiters, and one hot Jupiter very close to its star (WASP-12) has been observed with its orbit shrinking due to this effect. Most observed hot Jupiters are too far from their star for this effect to be important, but additional, very close-in hot Jupiters may have been destroyed by this mechanism."*

A Celestial Treat

As a regular subscriber to *Sky & Telescope*, I always look forward to Mathew Wedel's Binocular Highlight column. Viewing the brilliant Double Cluster in Perseus (NGC 869 and NGC 884) is always fun with my 7×50 binoculars and my 12.5-inch f/5 reflector. Adding NGC 957 and Trumpler 2 with red giant HD 16068 to my evening's list of planned objects, as mentioned in "Roadside Attractions" (*S&T:* Nov. 2022, p. 43), has been a nice treat.

Thank you, Matt!

Ted Harp
Tuttle, OK

Angling for an Angelfish

In "Riding the Radcliffe Wave" (*S&T:* Jan. 2023, p. 26), Brian Ventrudo states that the Lambda Orionis Nebula, Sharpless 2-264, is "too faint to spot visually." But this emission nebula is on Chris Beckett's "Wide-Field Wonders" observing list in RASC's *Observer's Handbook*. Beckett calls it the Angelfish Nebula and recommends using a hydrogen-beta filter.

My first observation of Sharpless 2-264 was at a remote, high-altitude site in interior British Columbia in 2004, using my 4.1-inch Astroscan rich-field telescope and a Lumicon ultra-high-contrast (UHC) filter. Jim Failes and I both saw two parts of Sharpless 2-264: a section southwest of 40 Orionis and a large section southeast of 37 Orionis. The latter part extended halfway to Bellatrix (Gamma Orionis). This was the last object of the night, and the Astroscan's optical window fogged up before we could attempt other sections of the huge nebula.

Our earlier observation of the Witch Head Nebula (IC 2118, also in Ventrudo's article) was what made that night a lifetime memory. Unfiltered, since it's a reflection nebula, we could see most of the nebulosity plotted on Roger W. Sinnott and Michael Perryman's *Millennium Star Atlas*. There was some curvature and a sharper edge on the side facing Rigel. Unfiltered 7×50 binoculars didn't reveal either nebula but showed some of Barnard's Loop.

In 2012, my backyard observatory's 16-inch Newtonian at 76× magnification with the UHC filter detected the edge of Sharpless 2-264 "by sweeping several

JOANNA FERRARI

fields west from Lambda Ori until the milky background turned to blacker sky," according to what I wrote at the time.

Alan Whitman
Okanagan Falls, British Columbia

Back to Astronomy

I found John Wolfram's Focal Point "A Telescope for the Times" (*S&T:* Nov. 2022, p. 84) to be a lovely and very relatable telling of a rekindling of the love of amateur astronomy. I too started this hobby as a youngster and have the same telescope I bought myself as a teenager 20 years ago. Like Wolfram, in recent years I dove back into the hobby, buying a new scope and getting into astrophotography on top of visual astronomy. It really was like picking back up an old childhood friendship. I'm also thankful I took the leap to get a new telescope, and I agree that this is an incredible time to be an amateur astronomer.

Katelyn Beecroft
London, Ontario

Legacy Cameras

I appreciated seeing a picture of the Legacy Camera CCD chip and the brief description of how the data were collected in Karen Masters' "The Never-ending Survey" (*S&T:* Jan. 2023, p. 20). I would love to see a survey article in *S&T* on newer camera designs such as those on Pan-STARRS, the Vera C. Rubin Observatory, and the James Webb Space Telescope, and the data science associated with them. Who knows, some inventive amateurs may come up with interesting projects that complement what the professionals are doing.

I appreciate what the Alfred P. Sloan and W. M. Keck Foundations have done for astronomy. I hope some newer wealthy individuals can see the importance of astronomy to humanity.

Vinai Varanyananda
Bangkok, Thailand

Cosmic Appreciation

I'm writing to express my appreciation for David Grinspoon's Cosmic Relief column. At first, I was intrigued but skeptical. Soon, however, I was completely won over.

His columns are engaging, imaginative, and informative and have become a favorite of mine.

Thanks, David.

Stuart White
Albuquerque, New Mexico

FOR THE RECORD

- In "What Makes a Good Planetary Telescope" (*S&T:* Jan. 2023, p. 58), the amount of light in the Airy disk of a telescope with a 33% central obstruction is not 68%, with 32% going into the diffraction rings. The correct percentage is 65% of light concentrated in the Airy disk, with the remaining 35% going into the diffraction rings.

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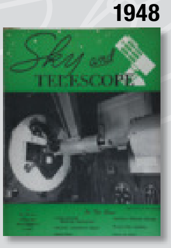
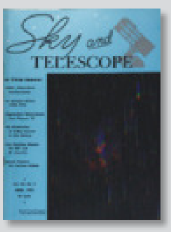
75, 50 & 25 YEARS AGO by Roger W. Sinnott

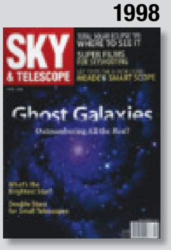
1948



1973



1998



April 1948

Gauging the Earth "The annular eclipse of May 8th-9th is getting almost as much attention as total eclipses of the sun usually do. It is going to help measure the size and shape of the earth with great accuracy. The National Geographic Society, the Army's Map Service [and other agencies are] sending expeditions to seven observing points in Burma, Siam, China, Japan, Korea, and the Aleutians.

"By timing exactly the instants when the moon first contacts the sun, when the ring of light around the moon first appears and first disappears, and when the eclipse is just over, as seen from the various stations, the scientists will be able to compute how far apart their observing positions are with errors not exceeding 150 feet."

In those days, star sights with a sextant yielded positions accurate to about a mile. LORAN radio navigation was not even that good.

April 1973

Gegenschein "Pioneer 10, launched on March 3, 1972, on a 620-million-mile journey to Jupiter, is the first space probe to explore the outer solar system beyond the orbit of Mars. [One instrument is making] periodic maps of the diffuse skyglow . . .

"A puzzling, often-studied feature of the skyglow is the gegenschein or counterglow, which is seen as a gradual brightening opposite the sun from the observer. The gegenschein has been attributed to backscattering by dust particles in interplanetary space or to various Earth-associated phenomena such as gas or dust tails. . . .

"[Measurements] taken when Pioneer 10 was 5.8 million miles from Earth and 1.011 astronomical units from the sun, showed . . . that the gegenschein was still there . . . Since the antisolar direction from the spacecraft was not the same as the antisolar direction from Earth, it is evident that the gegenschein is not associated with the earth."

April 1998

More Runaway Stars "Our mental image of the Virgo Cluster underwent a shakeup last year when the Hubble Space Telescope discovered that trillions of stars lie *between,* rather than merely *within,* the grouping's individual galaxies . . . Further signs of Virgo's intergalactic stars are now reported by Roberto H. Méndez (Munich University Observatory) and his colleagues in *Astrophysical Journal Letters* for December 10, 1997.

"The astronomers used the 4.2-meter William Herschel Telescope to seek planetary nebulae within a blank, 50-square-arcminute patch of the Virgo Cluster's core. A planetary nebula can be seen only for a few thousand years of a star's multibillion-year life, and only the brightest planetaries can be detected at the cluster's distance (50 million light-years). Consequently, the 11 planetaries found by Méndez's team may indicate that as many as half of the Virgo Cluster's stars are intergalactic."

SPACE

The Webb Telescope's Distance Record Is Official

ASTRONOMERS USING THE James Webb Space Telescope (JWST) have confirmed the most distant galaxies ever observed. Some formed just 330 million years after the Big Bang, when the universe was a mere 2% of its current age.

These new results, based on highly detailed spectroscopic measurements, provide concrete distances to galaxies first revealed in Webb images. "It was crucial to prove that these galaxies do, indeed, inhabit the early universe," says Emma Curtis-Lake (University of Hertfordshire, UK). "It's very possible for closer galaxies to masquerade as very distant galaxies."

Curtis-Lake is part of the JWST Advanced Deep Extragalactic Survey (JADES), a group that has been given a month's worth of observing time spread over two years to take spectra of distant galaxies. The first part of this effort saw them observe an area of the night sky in and around the famous Hubble Ultra Deep Field (HUDF). (The team is still in the process of publishing these data.)

Spectra of distant galaxies have a distinct cut-off point, called the *Lyman break*, at 91.2 nanometers; intergalactic hydrogen absorbs any light at shorter wavelengths. Because the ongoing expansion of the universe stretches the wavelength of light from galaxies in the early universe, it shifts their Lyman breaks, too. Thus, the longer the wavelength at which a galaxy appears to drop off in brightness, the older and more distant it is.

Broadband images taken at multiple wavelengths can reveal the Lyman break, which is how astronomers first pinpointed several distant galaxies. However, galaxies may appear to "drop out" at shorter wavelengths for other reasons, such as the enshrouding effects of dust. Spectroscopic measurements can confirm that a drop in brightness is indeed due to a galaxy's distance.

The JADES team collected up to 28 hours of data on 250 different galaxies using Webb's Near Infrared Spectrograph. They hit the jackpot on four of them: The galaxies are all beyond redshift 10, and two of them have a redshift around 13, meaning they formed as early as 330 million years after the Big Bang.

Studying these galaxies is a crucial part of working out how we arrived at the universe we see today. "It is hard to understand galaxies without understanding the initial periods of their development," says team member Sandro Tacchella (University of Cambridge, UK). "As with humans, so much of what happens later depends on the impact of these early generations of stars."

Michael Strauss (Princeton University), who wasn't involved in the research, is excited to see the results: "It's completely amazing that we are measuring spectroscopic redshifts for galaxies at a redshift of 13, looking back to the first few hundred million years of the universe's history," he says. "We're just starting to probe what is often called the 'Cosmic Dawn' with these observations, and who knows what the next year — much less the next 20 years — with JWST will teach us."

■ **COLIN STUART**

MISSION UPDATE

Trio of Spacecraft Launch for the Moon

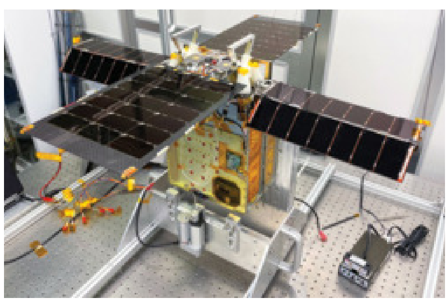
THREE MISSIONS ARE moonbound, after a SpaceX Falcon 9 rocket lit up early-morning skies over Florida on December 11th.

The launch carried the Hakuto-R Mission 1 lander, built by the Japanese company ispace; the Rashid lunar rover fielded by the United Arab Emirates Space Agency; and NASA's Lunar Flashlight orbiter.

Hakuto (meaning "white rabbit" in Japanese) will attempt to land in Atlas Crater near Mare Frigoris. As a technical demonstration mission, the solar-powered lander will operate for approximately 14 days, or one lunar day (from local sunrise to sunset).

The Hakuto R lander will deliver the Rashid rover to the lunar surface. The four-wheeled, 10-kg (22-pound) craft will also operate for one lunar day, carrying a microscopic imager for analyzing lunar dust, a Langmuir probe system for examining the plasma that surrounds the Moon, and a thermal imager for study of the surface.

"The mission's instruments are designed to study the lunar regolith in great detail," says Dimitra Atri (New York University Abu Dhabi). "Data from the Langmuir probe aboard the rover will help [us] understand how solar charged particles interact with the lunar regolith. And based on data from the microscopic imager, we plan to create a replica of the lunar regolith in our lab and study its properties."

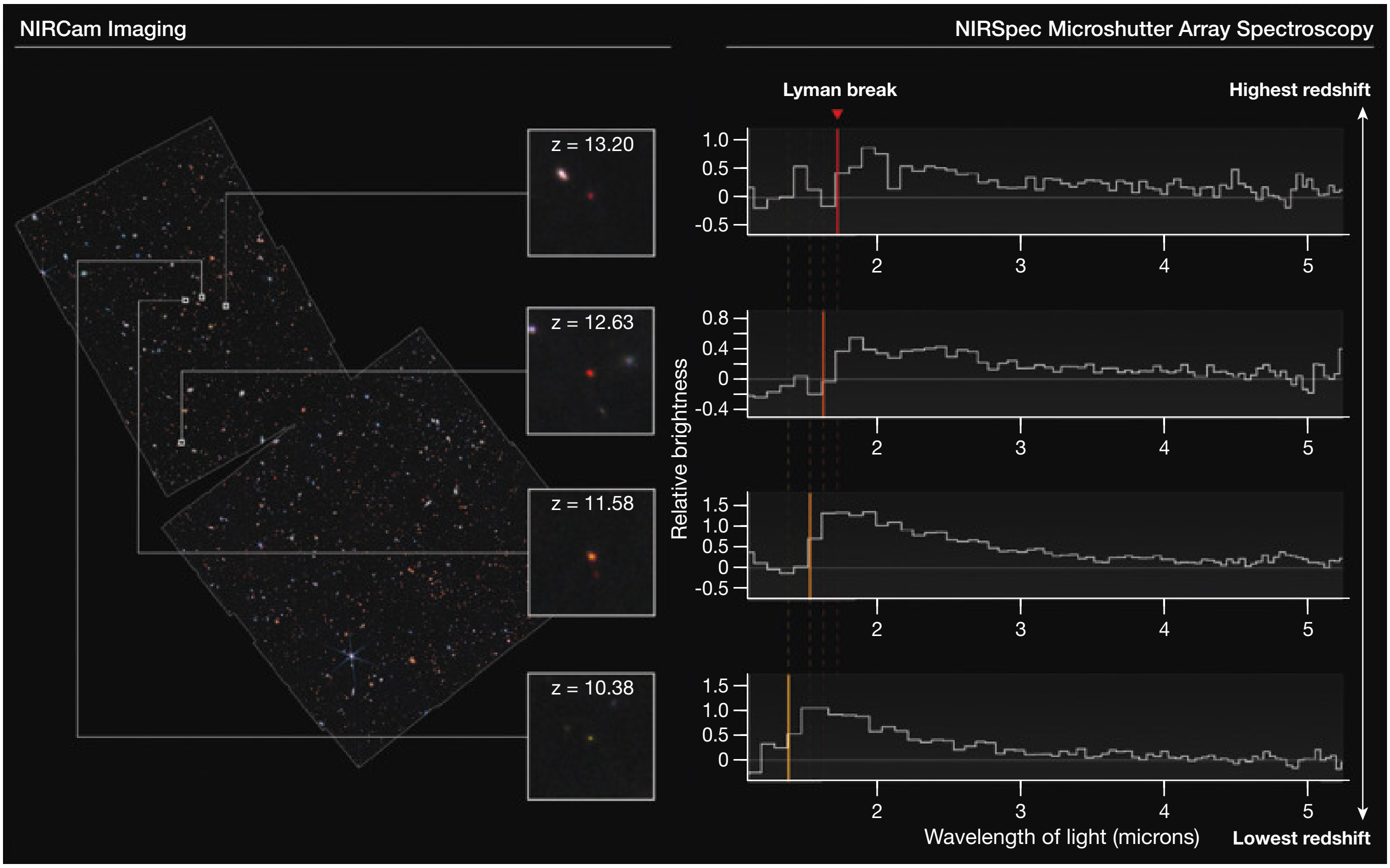


▲ The Lunar Flashlight CubeSat unfolded its solar panels in a clean room.

NASA / JPL-CALTECH

Hitching a ride with these missions is the Lunar Flashlight CubeSat, originally intended to launch aboard Artemis 1 last November. The satellite has already been released from its dispenser and has communicated with mission controllers. Once at the Moon, it will enter a *near-rectilinear halo orbit*, taking it as close as 15 kilometers (9 miles) to the lunar surface, and as far away as 70,000 kilometers. The close approach will enable the four laser reflectometers on this briefcase-size spacecraft to map out the water ice distribution on the Moon's surface. The CubeSat, along with the rover-carrying lander that it's accompanying, will arrive in lunar orbit around May 2023.

■ **DAVID DICKINSON**



▲ The Webb Telescope focused on an area in and around the Hubble Ultra Deep Field, collecting images and spectra that confirmed the extreme distance to four galaxies. The farthest one resided in a universe only 330 million years old.

DIAGRAM: IMAGE: NASA / ESA / CSA / STSCL / M. ZAMANI (ESA / JWST), LEAH HUSTAK (STSCI); SCIENCE: BRANT ROBERTSON (UC SANTA CRUZ), S. TACCHELLA (CAMBRIDGE), E. CURTIS-LAKE (UOH), S. CARNIANI (SCUOLA NORMALE SUPERIORE) / JADES COLLABORATION; SIMULATION FRAME: N. FISCHER / H. PFEIFFER / A. BUONANNO (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS) / SIMULATING EXTREME SPACETIMES (SXS) COLLABORATION

GRAVITATIONAL WAVES

Black Hole Merger Challenges Astronomers

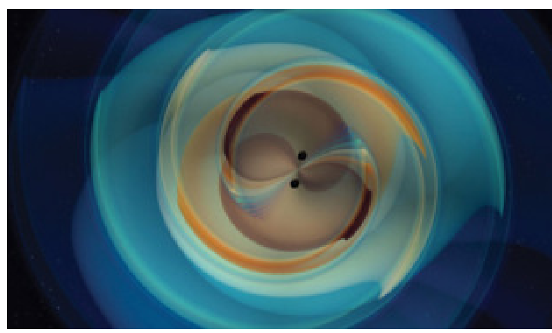
THE GRAVITATIONAL-WAVE signal known as GW190521 represents the collision of a roughly 90-solar-mass black hole with a 65-solar-mass one. The event has long excited astronomers, because exploding stars shouldn't create black holes with masses between roughly 50 to 120 Suns.

With only about 0.1 second of data, researchers have fit a whole slew of solutions to GW190521's signal. Astronomers initially settled on describing GW190521 as the merger of a pair of big black holes orbiting each other at wonky angles, causing the plane of their nearly circular orbit to wobble around. But others have instead considered highly elongated orbits, head-on collisions, or proposed that the mass estimates are just wrong.

Publishing November 17th in *Nature Astronomy*, Rossella Gamba (Friedrich Schiller University Jena, Germany) and colleagues threw their hats into the ring. Instead of assuming the black holes began paired, they looked at what would happen if the black holes grabbed hold as they flew by each other. A couple of close passes and a final collision suffice to match the data. The researchers estimate that such a capture is the likely explanation *unless* inspiraling orbits like the one initially assumed happen 4,300 more often than captures.

But we don't actually know yet how likely those different scenarios are. "If I see something out of the corner of my eye that looks a lot like a tiger and less so like a basketball, I would still likely infer what I saw was a basketball, because they are much more prevalent than tigers," explains LIGO astrophysicist Zoheyr Doctor (Northwestern), who wasn't involved with the current study. "The same could be true here: The data may look most like a hyperbolic encounter, but that could be counterbalanced if hyperbolic encounters are rare compared to other explanations."

We'll probably never know the exact nature of GW190521, but we might someday detect enough similar signals to say how likely it is that this event came from one or the other category.
■ CAMILLE M. CARLISLE



▶ Spacetime ripples from GW190521, the most massive binary black hole collision observed.

STARS

Gamma-ray Burst Surprise

GAMMA-RAY BURSTS ARE thought to come in one of two flavors — those that last two seconds or less come from neutron star mergers while longer ones herald the supernovae of massive stars. But GRB 211211A, a minute-long blast of gamma-rays that came from more than 1 billion light-years away, blurs that distinction.

The Fermi Gamma-ray Space Telescope caught this burst on December 11, 2021, recording a strong pulse of radiation that lasted 13 seconds, followed by a weaker echo 55 seconds long. But calling GRB 211211A "long" is akin to calling a tomato a fruit — while its gamma-ray emission is indeed longer than two seconds, it appears to have a different origin than other long GRBs.

Eleonora Troja (University of Rome) and Jillian Rastinejad (Northwestern University) led follow-up observations, reported in two separate articles in the December 8th *Nature*, showing more visible-light and infrared emission than expected relative to the gamma rays and X-rays. The longer-wavelength emission was bright enough to indicate a *kilonova*, the explosion that follows a stellar merger. A team led by Alessio Mei (Gran Sasso Science Institute, Italy) also reported in *Nature* that the GRB's long-lasting high-energy radiation supports the kilonova scenario.

"Just as a supernova links long gamma-ray bursts to the collapse of massive stars, a kilonova is the smoking gun for a compact binary merger," writes Luigi Piro (National Institute for Astrophysics, Italy) in an accompanying perspective article.

However, the length of the burst is hard to explain in this scenario. Gamma rays from stellar mergers are thought to come from the disk of material that temporarily surrounds and feeds the merged star, and colliding neutron stars make a disk too small to power more than a second or two of gamma rays. Jun Yang (Nanjing University, China) and colleagues therefore propose in the same issue of *Nature* that a "hybrid" collision between a neutron star and a white dwarf created an extremely magnetic neutron star known as a *magnetar* before collapsing into a black hole.

Troja's team, though, disagrees that the observations require a white dwarf. "I'd say that the origin of these long GRBs is still very much open and debated," Troja says.

■ MONICA YOUNG

MISSION UPDATE

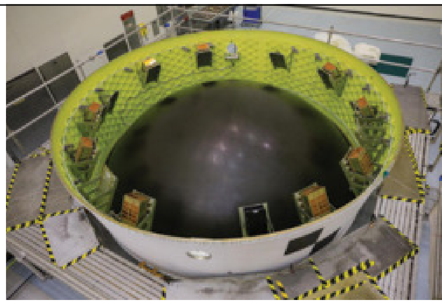
The Status of Artemis 1 CubeSats

THE HISTORIC ARTEMIS 1 mission (*S&T:* Mar. 2023, p. 8) carried with it 10 much smaller payloads to lunar orbit and beyond. As secondary payloads, such CubeSats are notoriously difficult to field — some 50% of those launched never complete their missions. But the ones aboard Artemis 1 have fared slightly better: As of press time, six of the 10 CubeSats are (or are on track to be) successful.

ArgoMoon: This joint NASA and Italian Space Agency (ISA) demonstrator successfully photographed the interim stage that placed the rocket on a Moonbound trajectory. It also sent back images of Earth and the Moon.

BioSentinel: This NASA mission carries budding yeast on an 18-month mission to study the effects of radiation on life. Although the satellite began to tumble shortly after deployment, the team was able to reestablish control.

EQUULEUS: The Japan Aerospace Exploration Agency (JAXA) built the Equilibrium Lunar-Earth Point spacecraft to observe lunar impact flashes



▲ Ten CubeSats are nestled in the ring-shaped stage adapter, which later connected the Orion capsule to the SLS rocket.

NASA / CORY HUSTON

and study Earth's inner magnetosphere. JAXA has reported that the steam-powered spacecraft has successfully completed its lunar flyby and is now headed to its destination at the L_2 Lagrange point beyond the Moon.

LunaH-Map: The Lunar Polar Hydrogen Mapper will look for water ice in the permanently shadowed polar regions of the Moon. The spacecraft is healthy and has already collected data on the lunar surface, but the team is struggling with propulsion problems.

Lunar IceCube: Also on the hunt for lunar water ice, this mission made contact following deployment, but no further updates have been issued.

Team Miles: Built to demonstrate a hybrid thruster system and deep space communications, Team Miles has sent back radio signals. Like Lunar IceCube, there have been no further updates.

While operational post-launch, the **LunIR** satellite was unable to demonstrate remote-sensing technology for lunar science, sending back a weaker-than-expected signal. And three missions are missing from action entirely:

CuSP: The Cubesat for Solar Particles was built to demonstrate space weather data collection in heliocentric orbit, but while CuSP was initially deemed operational, its first contact contained anomalies. The team since lost contact but is still attempting communications as of press time.

OMOTENASHI: Communications from JAXA's small lunar lander — officially named Outstanding Moon Exploration Technologies demonstrated by Nano Semi-Hard Impactor — were unstable early on, and the spacecraft began tumbling. The team has declared the payload lost.

NEA Scout: NASA's Near-Earth Asteroid (NEA) Scout was to deploy a solar sail and rendezvous with the small asteroid 2020 GE in late 2023, but the mission never phoned home.

■ DAVID DICKINSON

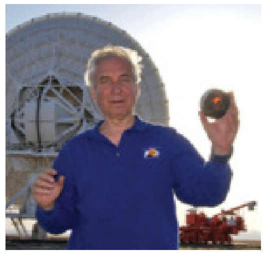
OBITUARY

Jay Pasachoff (1943–2022)

CHAIR OF THE ASTRONOMY Department, Director of the Hopkins Observatory, and Field Memorial Professor of Astronomy at Williams College in Williamstown, Massachusetts, Jay M. Pasachoff succumbed to cancer on November 20th. Pasachoff was renowned for his research on the solar corona as well as his many published works.

Pasachoff was probably best known as one of the world's foremost eclipse chasers. Over six decades he traveled to see 75 solar eclipses, eventually catching 36 totals, 19 annulars, and 20 partials. According to Bill Kramer and Andreas Möller's international eclipse-chasers log, Pasachoff ranks #2 by number of solar eclipses of all types, #1 by number of totals, and #3 by cumulative time in the Moon's umbra.

After completing his education at Harvard and doing postdoctoral research there and at Caltech, Pasachoff settled into what would become a 50-year career at Williams College. He often brought students along on eclipse expeditions, gathering photometric and spectroscopic data on the inner corona. Quite a few of those former students are now astronomy professors at other institutions, which delighted Jay.



◀ Jay Pasachoff at the Jansky Very Large Array in New Mexico during a 2012 solar eclipse.

Pasachoff was prolific in both research and writing, including textbooks and popular articles. He was also active in many professional organizations, including the International Astronomical Union (IAU), the American Association for the Advancement of Science (AAAS), and the American Astronomical Society (AAS). He was elected to leadership positions in most of those groups and named Fellow of the AAS, AAAS, American Physical Society, and Royal Astronomical Society. Jay and his wife Naomi regularly welcomed colleagues, students, and friends into their home. The IAU named asteroids for both of them: 5100 Pasachoff and 68109 Naomipasachoff.

Among his many other honors, Pasachoff received the AAS Education Prize in 2003 for his textbooks and the Astronomical Society of the Pacific's Klumpke-Roberts Award in 2019 for his astronomy outreach.

I'm sure I won't be alone in raising a bottle of Corona beer to toast Jay's memory at the next solar eclipse.

■ **RICHARD TRESCH FIENBERG**

Read Fienberg's remembrance at https://is.gd/JayPasachoff.

MARS

Ancient Megatsunamis Tossed Martian Boulders

SCIENTISTS HAVE TRACED the origin of boulders found near NASA's first successful Mars landing: The rocks came from an impact that occurred billions of years ago in an ancient ocean, producing a mega-tsunami that carried them up onto the one-time shore.

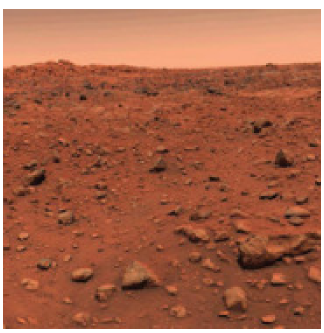
On July 20, 1976, Viking 1 landed in Chryse Planitia, a low-lying circular plain that might once have contained an ocean. But rather than seeing signs of water, Viking 1 found only boulders with unclear origins.

In 2016, Alexis Rodriguez (Planetary Science Institute) led a team that reported evidence of two megatsunamis, both occurring around 3.4 billion years ago in an ocean that then covered the north of the Red Planet. More recently, Rodriguez's group modeled the tsunamis in order to understand the impact craters that could have created them.

On December 1st in *Scientific Reports*, the team reports the most likely suspect for the first of these events: the 110-kilometer (70-mile) Pohl Crater about 900 km northeast of the Viking 1 landing site. That impact created a tsunami that carried debris generated in the post-impact shock wave.

"The marine floors would have been tossed up," Rodriguez says, "feeding the wave with sediments and probably aiding the development of a catastrophic debris flow front."

The megatsunami initially reached a height of about 500 meters (1,640 feet) and propagated inland to some 250 meters above sea level, aided by the low slope of the terrain. The slope also slowed the backwash, keeping most of the debris on land. The tsunami from the second impact later covered Pohl Crater.



◀ NASA's Viking 1 took this image of Mars in 1976, showing strewn boulders of unknown origin.

While both events happened during the Late Hesperian, a long-ago epoch of on-again, off-again seas, their exact timing is still uncertain.

■ **JEFF HECHT**

Hear a Martian Dust Devil

NASA's Perseverance rover has recorded the sound of a dust devil passing overhead. "Each SuperCam microphone recording lasts only 167 seconds, and we only perform on average eight such recordings a month," says Naomi Murdoch (University of Toulouse, France), who led the study published December 13th in *Nature Communications*. "So we got lucky!" The team estimates that the vortex was 118 meters (387 feet) tall and 25 meters wide. It traveled at a sedate 5 meters per second (11 mph), though the winds within the vortex whipped around at 25 mph on average. Listen here: **https://is.gd/DustDevil**.

■ **MONICA YOUNG**

PASACHOFF: JAY PASACHOFF / WILLIAMS COLLEGE; BOULDER-STREWN REGION ON MARS: NASA / JPL

 by Shannon Hall

SOFIA's End

NASA's SOFIA observatory came to an abrupt end last September, leaving many scientists despondent and a number of projects unfinished.

The Boeing 747 lifted toward the sky, taking off at a hefty pitch and shoving Jim De Buizer back in his seat. The goal was to reach 35,000 feet — and fast.

At that altitude, the pilots would ease up on the throttle and open a 4-meter-wide door in the side of the fuselage. It wasn't a death wish: They were exposing a 19-ton, 2.5-meter telescope to the starry sky.

It was May 26, 2010, the first night observing with the world's largest airborne telescope — otherwise known as the Stratospheric Observatory for Infrared Astronomy, or SOFIA — and De Buizer had goosebumps. "You're taking off to get the first photons for an observatory ever," De Buizer says. "And that's just pure adrenaline that whole entire time."

From the ground, water vapor in our atmosphere blocks most infrared light. But at its maximum altitude of 45,000 feet, SOFIA flies above 99% of that water vapor, giving it unique access to the far-infrared part of the electromagnetic spectrum. Since the project became fully operational in 2014, it has been the only telescope that could study celestial objects at these wavelengths.

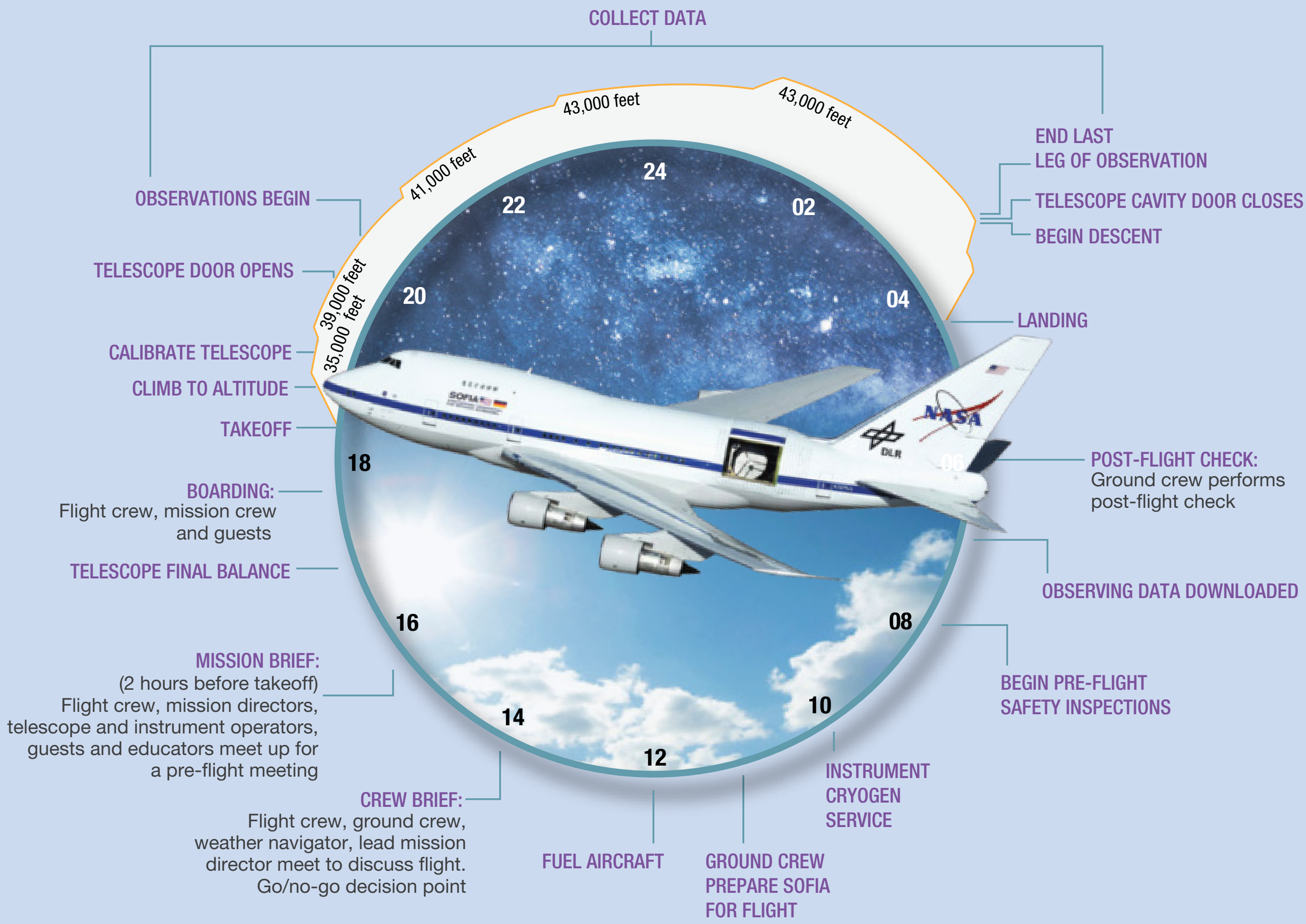
"It's a one-of-a-kind observatory," says Alfred Krabbe (University of Stuttgart, Germany), the director of the German SOFIA Institute. (SOFIA is a joint mission between NASA and the German Aerospace Center, or DLR.)

So when De Buizer and his colleagues pointed the telescope toward Jupiter on that first night, they probed depths of the planet that had never been seen before. The composite image (obtained by De Buizer on the ground after only an hour's sleep) revealed heat that had been trapped since the planet's formation and was now pouring out through holes in the clouds.

The image exceeded his expectations. And by the time SOFIA completed its development phase in 2014, he and many other scientists were looking forward to what they thought would be a 20-year run, giving an unprecedented view of the infrared sky — a part of the spectrum rich with information about planets, newborn stars, and galaxies.

◀ **THE KEYHOLE** This composite image shows magnetic fields (swirling lines) detected by SOFIA in the Keyhole Nebula, part of the larger Carina Nebula, or NGC 3372. The magnetic fields have the same orientation to those in the larger cloud complex except in the big loop structure at center, where the field aligns with the direction of Eta Car's powerful winds. The alignment confirms that stellar feedback can disturb magnetic fields in star-forming clouds, and that Eta Car likely made the loop structure. The background image is from the European Southern Observatory's 3.6-meter telescope on La Silla. The inset by astrophotographer Steve Mazlin gives a clearer sense of the nebula, taken using hydrogen-alpha (red) and O III (blue) filters, with a green channel synthesized from the other two.

SOFIA: NASA / SOFIA SCIENCE TEAM / Y. SEO / ESO; INSET: STEVE MAZLIN / SSRO / PROMPT / CTIO



▲ **A DAY IN THE LIFE OF SOFIA** The daily operations timeline crammed everything necessary for a safe and successful observing run into a single 24-hour period. SOFIA flew up to four days each week.

But merely eight years later, on April 28, 2022, NASA and DLR announced that they would shut SOFIA down.

In its short lifetime, the observatory discovered water on sunlit portions of the Moon. It measured magnetic fields in stellar nurseries and distant galaxies. It followed up and vastly improved on many discoveries made by the Herschel Space Observatory, which operated at far-infrared wavelengths from 2009 to 2013. And it even measured atomic oxygen in Earth's atmosphere, helping climate scientists refine their models of climate change.

But SOFIA still fell short of expectations. Over its first five years in operation, the observatory did not generate large numbers of high-profile results (measured by the number of citations in scientific journals). That, along with the observatory's high operating price tag of $85 million per year — second only to the Hubble Space Telescope — forced NASA to decommission it.

So at the end of September 2022, the Boeing 747 lifted into the air and the telescope captured its last images.

Many scientists were left heartbroken and downright angry, frustrated by a swift decision they felt was based on outdated information. The shutdown also left many projects unfinished, without any alternative instruments to continue them: There is no longer an operating far-infrared observatory.

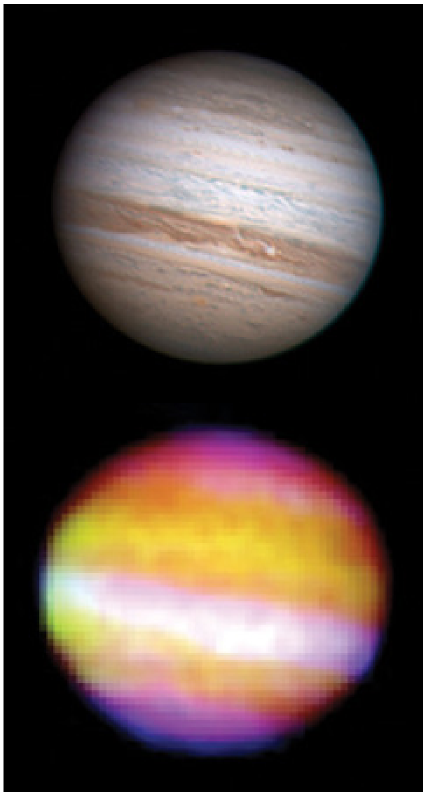
"To rip this gigantic hole into the coverage of the electromagnetic spectrum is — in my eyes — not defendable," says Bernhard Schulz (also University of Stuttgart), the top German representative on the SOFIA science team. "It is rather a scientific crime than anything else."

"A Crazy Idea"

SOFIA came from a long line of airborne astronomy. As early as the 1920s, astronomers used biplanes to chase solar eclipses. In 1968, NASA started using a Learjet equipped with a 30-centimeter telescope to study Jupiter and nebulae.

The next year, the agency began planning the Kuiper Airborne Observatory (KAO), which featured a 36-inch telescope that stared through a hole in the roof of a military transport

SOFIA STATUS AND FUTURE PROSPECTS 2022 / NASA / SOFIA / MONIKA ROSE



◀ **A NEW VIEW OF JUPITER** Bands appear on Jupiter at both visible *(top)* and infrared *(bottom)* wavelengths, but this composite infrared image from SOFIA's first-light flight in 2010 includes wavelengths either difficult or impossible for ground-based instruments to observe. The white strip is a relatively transparent cloud band through which Jupiter's interior heat shines.

INFRARED: NASA / SOFIA / USRA / FORCAST TEAM / JAMES DE BUIZER; VISIBLE: ANTHONY WESLEY

aircraft. KAO flew for 20 years and made several major discoveries at infrared wavelengths, including the first sightings of the rings of Uranus and a definitive identification of an atmosphere on Pluto. KAO retired in 1995 to make room for its successor, SOFIA.

In many ways, these airborne observatories have an edge over both their space- and ground-based counterparts.

Unlike space-based observatories, they can land. That means instrumentation can be repaired or updated with improving technology. Satellites, on the other hand, carry outdated equipment designed long before launch and can't be fixed should something go wrong. And unlike ground-based counterparts, plane-based telescopes can fly above most of the atmosphere and to any location on Earth, enabling them to observe objects in both hemispheres and seek the best paths across the globe for occultations. In 2015, for example, SOFIA watched Pluto slide across the face of a distant star — a rare celestial alignment that allowed scientists to collect crucial data on the dwarf planet's atmosphere.

But for all the upsides, stabilizing a telescope on such a bumpy platform is a tough problem. "It's a crazy idea," Schulz says. "There's nothing less stable than an airplane."

For SOFIA, engineers spent years finding ways to direct airflow around the hole in the fuselage to prevent the telescope from shaking uncontrollably. They also sat the telescope on 24 air springs and three dampers, to absorb most of the plane's vibrations. The bearing floats on a very thin film of oil to offer soft support. And the telescope utilizes gyros to measure its own movement, counteract that movement, and steady itself. It's no wonder the original completion date (which was supposed to be 2001) was pushed back to 2014. The budget also ballooned from $265 million in 1997 to $1.1 billion by the time SOFIA finally became fully operational.

Fields at Play

SOFIA filled the gap left by Herschel's decommissioning in 2013, covering a range that subsequent high-profile observatories like the James Webb Space Telescope and the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile don't. And that gap is crucial.

When astronomers observe the energy output of star-forming galaxies, they find that roughly half is in the form of mid- to far-infrared radiation. "So if you didn't study the universe in the far-infrared, you would only get half the picture," says Naseem Rangwala (NASA Ames Research Center), SOFIA's project scientist. "There's so much at this wavelength range that's waiting to be discovered."

Take the question of star formation. To build a star, the universe needs two major ingredients (gas and dust) plus a blend of things like gravity and turbulence. Astronomers know the basics of how a star is born, but according to most computer models, star formation should occur at a much faster clip than the one we observe. So what's slowing it down? Researchers have long wondered if magnetic fields — which are so mysterious they were ignored in early computer models — could be the culprit.

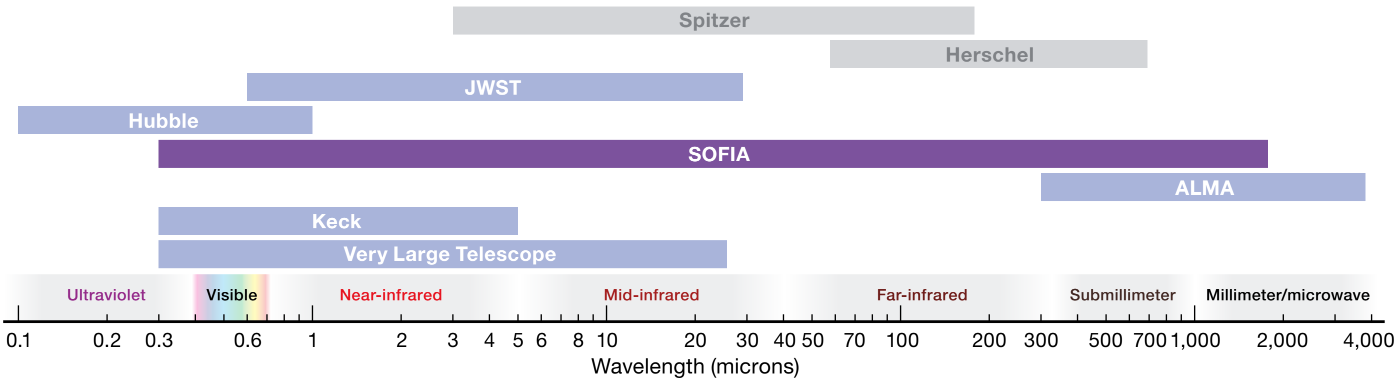
To find out, scientists built an instrument for SOFIA called HAWC+, which maps the alignment of incoming light waves and can reveal crucial information about magnetic fields. When Thushara Pillai (Boston University) used HAWC+ to observe a nearby cluster of roughly 50 young stars, she was able to pinpoint the zone where gravity becomes the dominant player. Here, magnetic fields suddenly change orientation: Instead of supporting gas filaments against collapse, they succumb as gravity takes over and drags the gas (and the magnetic fields trapped inside) to become channels flowing into a central, star-forming hub. It's gravity's conquest of magnetic fields that allows stars to form.

The finding suggests that magnetic fields are a key player in star formation. But one cloud alone cannot explain why star formation is so slow. So Pillai started a SOFIA survey to repeat this experiment on a much larger sample.

Meanwhile, her colleagues used the same instrument to

Airborne Telescopes

Planes aren't the only way instruments take to the skies: Scientific balloons also have a long, successful history (*S&T:* Feb. 2018, p. 16). These balloons typically fly between 96,000 and 127,000 feet above sea level, can carry the equivalent of three cars' weight in gear, and stay aloft for anywhere from 2 hours to 2 months. But they don't have their own propulsion; they must follow the winds. This is not as prohibitive as it sounds: Campaigns over Antarctica, for instance, utilize the predictable patterns of seasonal stratospheric winds to plan observing targets in advance.



▲ **INFRARED GAZE** SOFIA spanned wavelengths that other major facilities don't currently observe (the Spitzer and Herschel space telescopes have shut down). Balloons are often used for far-infrared studies as well, but they don't have a set wavelength range — it depends on the instruments flying — and so don't appear here.

map magnetic fields beyond the Milky Way. Consider M82, a so-called *starburst galaxy* undergoing an exceptionally high rate of star formation, akin to the universe's earliest galaxies. There, scientists discovered that the galactic wind blowing from the center of M82 is so intense that it drags the galaxy's magnetic field along with it — potentially explaining how the intergalactic medium in the early universe was initially seeded with a magnetic field (*S&T:* Sept. 2021, p. 22).

▼ **STAR FORMATION** This composite image of the Serpens South Cluster shows magnetic fields (streamlines) superposed on an infrared image. In the dense gas filament (center left), gravity has overcome the resistance of magnetic fields, dragging the gas and fields into an inward flow that fuels star formation.

"When I was a grad student, magnetic fields were something that we always put under the rug," Rangwala says. "Now we are producing textbook-changing results."

But the largest splash of all was perhaps water on the Moon. In 2020, SOFIA detected water in one of the largest craters visible from Earth. Scientists determined the concentration was 100 to 400 parts per million — roughly the equivalent of a 12-ounce bottle trapped in a cubic meter of lunar soil. While scarce, the water raises intriguing questions about how it persists and potentially migrates across the Moon.

Paul Lucey (University of Hawai'i, Manoa), one of the planetary scientists responsible for the detection, began a much larger SOFIA survey to map the Moon entirely. He wanted to better understand whether water can migrate and eventually supply the poles. That work is crucial for future missions to the Moon — including NASA's upcoming Artemis 3 mission, which will land near the lunar south pole.

If astronauts could recover water on the Moon, then it could be used for drinking water and converted into fuel, reducing the load future spacefarers must take in their ventures beyond Earth. "It changes the economics of space resources pretty substantially," Lucey says.

But Lucey's map won't be completed. Neither will Pillai's survey that might have pinpointed how star formation occurs. Both are victims of SOFIA's abrupt end.

Grounded

SOFIA's scientific output has long been questioned. In 2019, NASA commissioned a flagship review, which detailed the observatory's low productivity. Over its first five years of operations, for example, SOFIA produced roughly two dozen scientific papers per year. That is far too low for a project that costs NASA more than $80 million per year. Compare it to ALMA, which publishes about 500 scientific papers each year and cost the National Science Foundation $51 million in 2022. (Mind you, ALMA can work both day and night and typically observes half of the total hours in a year.)

In response to the flagship review, SOFIA brought in a

WAVELENGTH DIAGRAM: GREGG DINDERMAN / *S&T*; SERPENS SOUTH CLUSTER: NASA / SOFIA / T. PILLAI; NASA / JPL-CALTECH / L. ALLEN

new director, Margaret Meixner (then of the Space Telescope Science Institute), who ramped up scientific productivity. She hired postdoctoral researchers, ran multiple virtual conferences, and increased the total number of flights per week to four. (SOFIA couldn't fly every night of the week because of scheduled maintenance and the higher cost of additional crew.) Meixner even bolstered the amount of SOFIA data in archives to entice astronomers to dig through past observations and publish fresh papers on them.

In all, the observatory doubled its annual publication rate from 2019 to 2022. Its scientific output during that time was even on par with what the Herschel Space Observatory had achieved during its operations. "We hit all records in 2022: total number of annual publications, research hours achieved in flight, flight cadence — everything," Meixner says. "All the metrics were very high, which just demonstrates that SOFIA had really hit stride."

Meixner and her colleagues planned to document these changes in a second review that would take place in 2022, called the senior review. The team finished the draft early, certain that NASA would see a clear improvement. But NASA never looked at it.

In January 2022, NASA pulled SOFIA from the review, and in April, the agency announced they would shut down the observatory. That decision cited the 2020 decadal survey, which echoed the flagship review's argument that SOFIA is expensive to operate and does a limited amount of high-priority science.

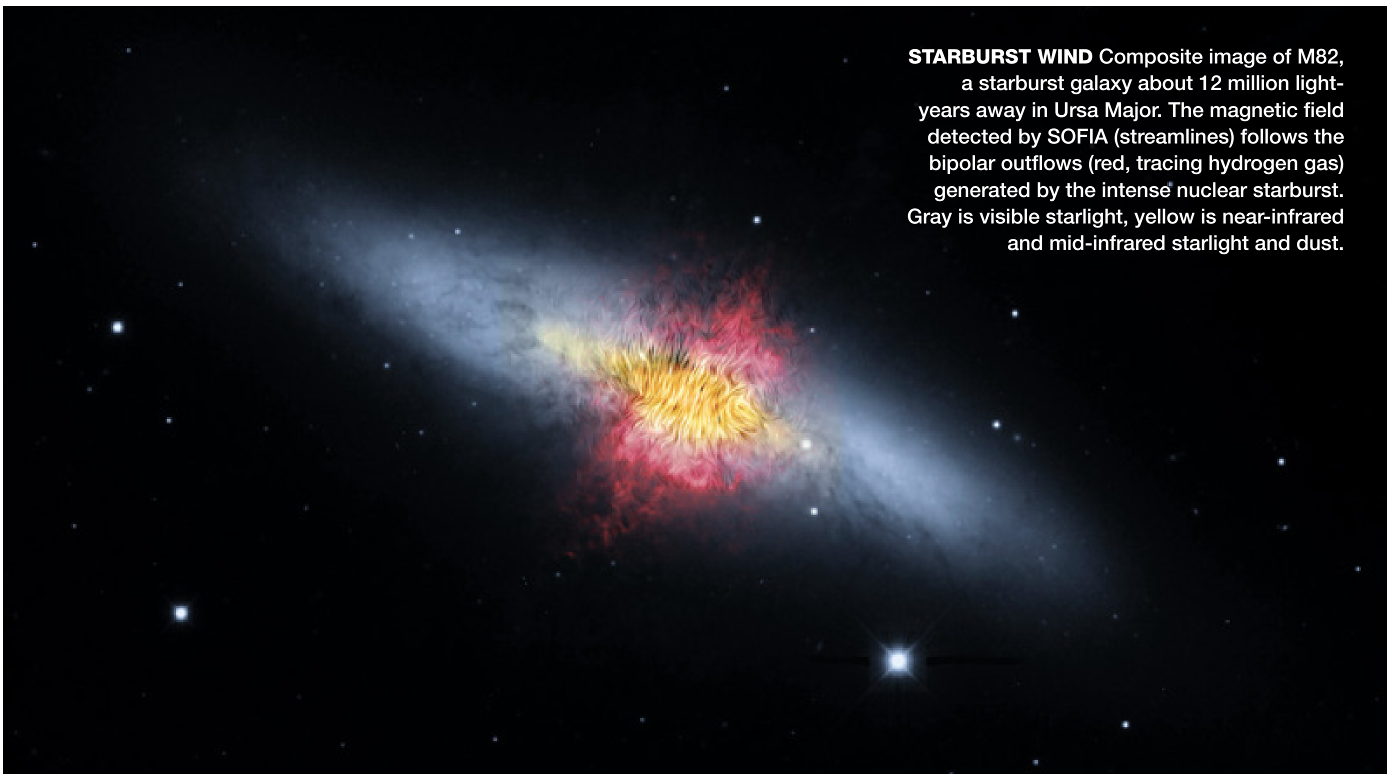
But the decadal survey did not include Meixner's directorship, the ramp-up in productivity over the last three years, or exciting results like Pillai's early magnetic-field work and Lucey's detection of lunar water. NASA's decision was therefore based on outdated data, critics say. One dissident even accused NASA of wanting to shut SOFIA down and trying to prevent the project from making its case.

But Paul Hertz (NASA), who was the Astrophysics Division Director when the decision occurred, says the decadal survey "found no evidence that SOFIA could, in fact, transition to a significantly more productive future." Nor is NASA ending SOFIA "early," as many SOFIA scientists assert, he adds.

Although SOFIA was capable of operating for 20 years, no prime mission lifetime was officially set early on, he argues. "It was assumed by NASA that the prime mission would match that of Hubble and Chandra (and subsequently Webb), which is five years," he says. The agency and project later formally recognized this five-year prime mission in the SOFIA Program Commitment Agreement that was signed in 2015.

That means that SOFIA's prime mission technically ended in 2019, five years after the observatory became fully operational. Following the flagship review at that time, NASA extended the mission for three years until 2022.

The limited prime mission, however, was not effectively communicated to the SOFIA team. Harold Yorke, who was SOFIA's Science Mission Operations Director from 2016 to 2020, says that NASA headquarters informed the project as late as 2018. (Yorke forfeited all documents when he retired from the project and is hesitant to assign a specific date, but he's certain the news came much later than the start of SOFIA.) There is even a Congressional record from 2018, which quotes a "prime mission lifetime of 20 years."



STARBURST WIND Composite image of M82, a starburst galaxy about 12 million light-years away in Ursa Major. The magnetic field detected by SOFIA (streamlines) follows the bipolar outflows (red, tracing hydrogen gas) generated by the intense nuclear starburst. Gray is visible starlight, yellow is near-infrared and mid-infrared starlight and dust.

NASA / SOFIA / E. LOPEZ-RODRIGUEZ; NASA / SPITZER / J. MOUSTAKAS ET AL.

The German Aerospace Center also appears to have been left out of the loop. Krabbe and his colleagues were shocked to learn the same news. "It was a one-sided decision," Krabbe says. "As far as I know, the German Aerospace Center never agreed to that."

The change was a major blow to the SOFIA project. "That was a death sentence," Schulz says.

Money Matters

The sad reality is that NASA doesn't have the money to fund every worthy project. "There has never been a budget where we could cover everything we would like to do," says Thomas Zurbuchen, who served as NASA's associate administrator for science until the end of 2022.

And SOFIA is far from cheap. Jet fuel, maintenance, and overhead for safe flight operations all cost money. In 2021, SOFIA accounted for 6% of the overall astrophysics budget, a larger share than any other program except for the Hubble Space Telescope. (Development of the James Webb Space Telescope is not included in the astrophysics program; it's a separate line item in the budget.) And NASA covers 80% of SOFIA's budget; DLR only supplies 20%.

"It just comes down to a numbers game," Lucey says. "So the astrophysics program, every dollar it spends on SOFIA is a dollar they can't spend on something else. And the amount of science per dollar is kind of low. It does great science, but just not enough of it for every dollar spent."

NASA runs a careful calculation of operating costs relative to scientific output, and the result has changed dramatically over the last three decades, Zurbuchen explains.

When SOFIA was first conceived in the 1990 decadal survey, it was a lot more complicated and expensive to send an observatory to space. So the solution seemed simple: Use an airplane to capture infrared science faster. But SOFIA wasn't fast enough. Space-based technology evolved at a rate that outpaced SOFIA's delays, allowing observatories like Herschel and Spitzer to launch in the interim.

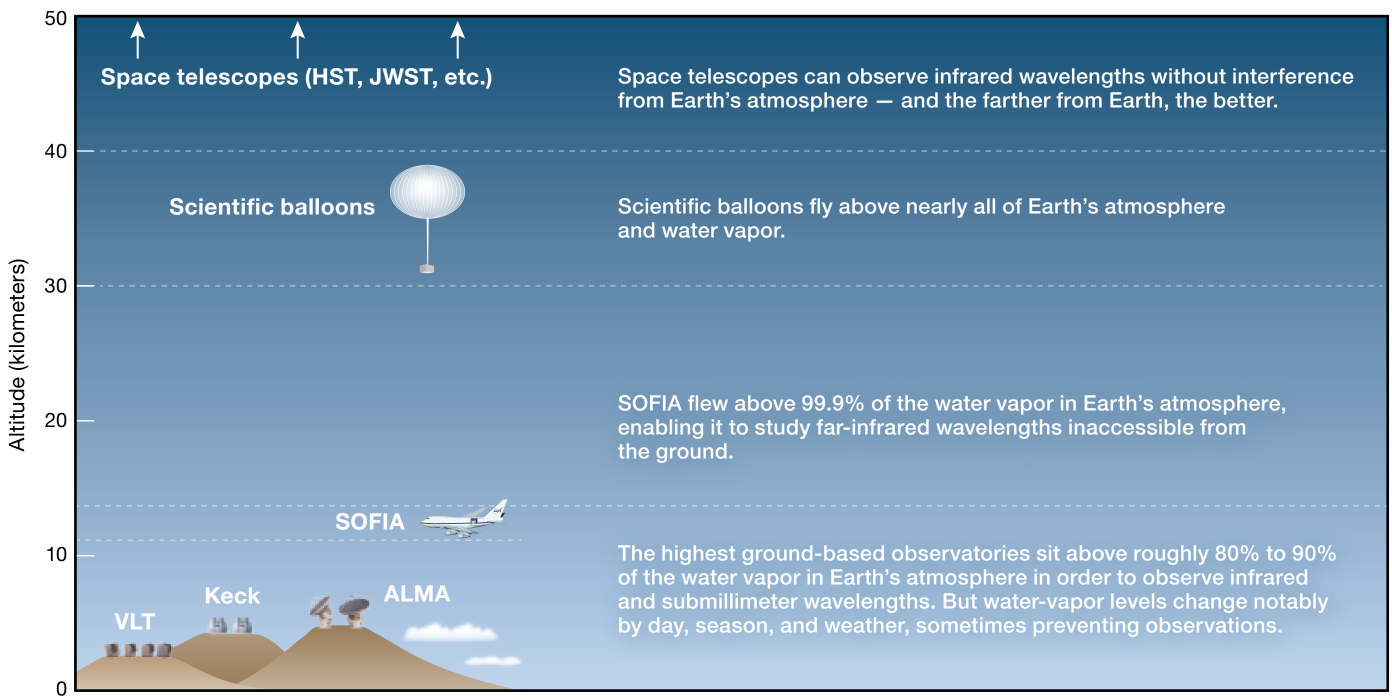
"There are science opportunities that have a window of opportunity, and if you miss it, it's going to get harder," Zurbuchen says. "And the case that was at the heart of SOFIA became less important."

That explains why SOFIA has often been on the cutting block. In 2006, NASA tried to cancel the project, but Congress and Germany forced the agency to restore it. In 2014, NASA again threatened SOFIA's funding — just 11 days after the observatory became fully operational. And NASA continued to try to nix SOFIA in 2020, 2021, and 2022, until it finally succeeded.

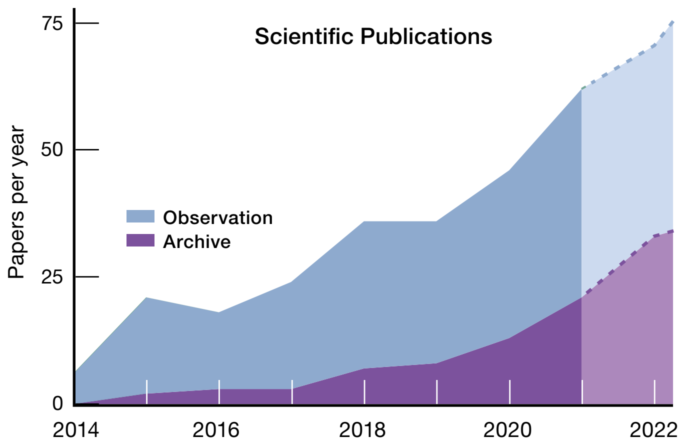
Many argue, however, that you can't look at the yearly budget alone. Yes, SOFIA is more expensive to operate on a year-to-year basis than a satellite, but its overall expenses are much lower. The Hubble Space Telescope, for example, cost roughly $4 billion to build, launch, and operate for the first 8 years of its lifetime. SOFIA has only cost $1.8 billion. Other space-based observatories, on the other hand, have cost much less: The Kepler Space Telescope, which ran for 9 years, was only $704 million.

Although Meixner respects NASA's right to make this decision, she thinks that the numbers argument is flawed. "If they had let it go on for three more years, we would have

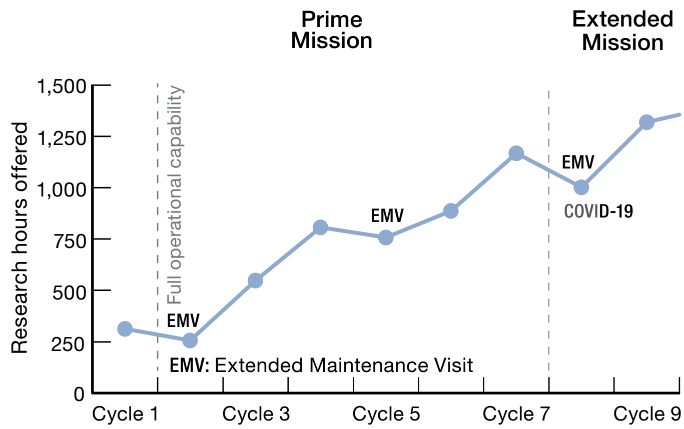
Observatories by Altitude



GREGG DINDERMAN / S&T



▲ **PERFORMANCE** Annual publications, including those based on mining SOFIA's data archive (purple), grew since full operations began in 2014. The lighter-shaded regions are projections based on the team's planned improvements, prior to the decision to shutter the program.



▲ **OBSERVING TIME** SOFIA's available observing time increased over the years, with impacts from maintenance and the pandemic. Cycle 1 began in mid-2013; after that, most observing cycles lasted about one year, beginning in the early part of the calendar year (except for 2020–22).

collected so much more data to increase the archive and also to increase publications," she says. "And, you know, it would have been a minor increase in total costs for the mission, but it would have been at a higher science return."

A Gap in the Spectrum

For many, the shutdown is heartbreaking. But this is natural, Zurbuchen notes. When the team that flew Cassini ended the mission by slamming the probe into Saturn, many cried. When the team that controlled Spitzer sent the last command to the probe, there were also tears. And when Opportunity died, people were literally sobbing. "The fact that there's an emotional component is what we expect," Zurbuchen says. "Our people really care for their missions. And SOFIA is not different."

But in this case, SOFIA's finale ended a 54-year-marathon of similar observatories and left a gap in the electromagnetic spectrum. "They just took the axe and just cut it," Schulz says.

Luckily, Lucey's lunar survey had already imaged several crucial locations, including the upcoming landing sites for the Artemis mission. The researchers will have enough data to nail down the behavior of water, but they won't have a measurement of every single point on the Moon at a number of times a day — the original goal.

"With a comprehensive data set, you'll make unanticipated discoveries," Lucey says. "We've learned from other wavelength regions that the places on the Moon that are sometimes the most interesting are very small and rare. So they're easy to miss."

The gap is more than an absence of infrared discoveries, though. It's also an absence of infrared astronomers.

Already, many young scientists are fleeing the field of far-infrared astronomy. That could be a major problem in the future. "Science in a way is still done a little bit like a medieval guild," Schulz says. In a guild, you have a master and an apprentice; in science, you have a professor and a student. The professor passes down expertise, including a lot of information that is not published in textbooks or scientific papers.

"When we are at the point where we have money again for a new infrared space mission, then we will have nobody who really knows how to work with the data or even how to build the instrumentation," Schulz says. Astronomers will have to re-invent the wheel.

But Hertz argues that it has never been a requirement or even an expectation that every wavelength has a mission operating at any given time. That's just not possible. "Missions come and go," he says. "And they always have over the history of NASA. And there's always gaps somewhere in the electromagnetic spectrum."

In many ways, that makes the archival data from SOFIA even more important. Pillai takes this optimistic tone, arguing that it will be the best available dataset until the next far-infrared observatory — even if it's incomplete.

And De Buizer (who was on the first-light flight and became SOFIA's planning and scheduling manager) agrees: "Astronomers are going to have our data to really sift through and mine and make new discoveries," he says. "So in that way, the legacy of SOFIA is exciting."

There is no question that SOFIA was unique. And because of that, scientists like De Buizer advanced the field of infrared astronomy. "Whatever next mission comes is going to be better because of SOFIA," De Buizer says. "In the sadness, I can take pride in that."

■ Contributing Editor **SHANNON HALL** is an award-winning freelance science journalist who lives 1 mile above sea level — and above approximately 18% of Earth's atmosphere.

FURTHER READING: Read up on milestones in airborne astronomy from the 1920s to 1990s: **https://is.gd/aeroastrohist**.

 by Ted Forte

Springtime Galaxy-*Hop*

Get your scope out and spend some time chasing galaxies in southern Virgo.

With its dense clustering of bright galaxies, sprinkled with multiple Messier objects, the central part of the Virgo Cluster (sometimes called the Virgo-Coma Cluster) is familiar territory for most deep-sky observers. Less traveled, perhaps, are the rich galaxy-hunting grounds of southern Virgo.

Bracketed between M61 in the north and M104 in the south is a patch of sky that, while less densely packed than "downtown Virgo," is still chock-full of worthy targets. Most of the galaxies here belong to the Virgo II Groups, which are alternately called the Virgo II Cloud, the Virgo Southern Extension, or the Virgo S Cloud. This vast region of space, off the southern edge of the Virgo Cluster, contains about 100 galaxy groups and individual galaxies. At least 50 of them are brighter than magnitude 12.5. In this tour we'll start in the north and meander south visiting the targets I think are best.

Starting at the Top

Our first stop is 2.5° east-southeast of M61. **NGC 4496** is an overlapping system that until recently astronomers thought

ESA / HUBBLE / NASA / T. BOEKER, B. HOLWERDA, DARK ENERGY SURVEY, DOE, FNAL / DECAM, CTIO / NOIRLAB / NSF / AURA, SDSS

possibly consisted of a colliding pair. However, new research indicates that the smaller galaxy is much more distant and not physically associated with the larger of the duo.

William Herschel likely encountered this target twice in the same sweep on February 23, 1784, recording it as different objects, which in turn led to two listings in the *New General Catalogue of Nebulae and Clusters of Stars* (*NGC*). But there's nothing at the position of his second observation, and astronomy historian Harold Corwin concludes that the two objects are equivalent. John Herschel observed the object that became NGC 4496 and noted it as double. (Hereafter, to differentiate father and son, I'll identify each Herschel by his first name.) However, the *NGC* doesn't list two designations for it even if it's identified as a double nebula. Some references, though, label the two galaxies either NGC 4496A and NGC 4496B or NGC 4496 and NGC 4505. Observing with my 18-inch Dobsonian at 197× (my standard setup unless otherwise noted) and under rural Arizona skies, I described this interesting object as faint (magnitude 11.4) but having visible structure and a close companion that appears as a knot.

From NGC 4496, let's swing 45′ west-southwest to **NGC 4457**. This 10.9-magnitude lenticular galaxy lies 63 million light-years from us. William described it in his standard shorthand as "pB, mbM" (pretty bright, with a much brighter middle). In my 18-inch, I see it as almost round, with only a slight northeast-southwest elongation. It has a very obvious core with a 13th-magnitude star just west of center. The galaxy also sports a faint outer ring, but that feature is probably not visible in backyard telescopes. I failed to detect any trace of it in my 30-inch Dob. NGC 4457 likely had a recent *minor merger* (when a significantly larger galaxy absorbs a smaller one), but I didn't notice any disruption through the eyepiece.

Continuing southeast a little less than 2° will put two remarkable galaxies into the field of view of a low-power eyepiece. The cores of **NGC 4527** and **NGC 4536** are 28′ apart and, at distances of 44 and 47 million light-years, respectively, the pair are actually fairly close neighbors. Despite their proximity, William discovered the two objects on separate sweeps about a month apart.

NGC 4527 and NGC 4536 are both large, bright galaxies. I see 10.5-magnitude NGC 4527, a nearly edge-on spiral, as very elongated with a bright core and a mottled appearance. Neighboring 10.6-magnitude NGC 4536 is a somewhat S-shaped spiral, the structure of which is hinted at in the eyepiece by two sweeping bright patches that curve around the core. I detected faint extensions at the northwestern and southeastern ends. Astronomers using Spitzer Space Telescope infrared data in 2011 unearthed evidence of an active galactic nucleus (AGN) in NGC 4536. This was an unexpected finding since the galaxy doesn't have a prominent bulge at visible wavelengths. Scientists have long assumed that AGNs are associated with galactic bulges, and so this result may contribute significantly to our understanding of how black holes and their associated AGNs affect galaxy evolution.

◀ **GALACTIC TROMPE L'OEIL** As with several targets discussed here, NGC 4496 has gone through several iterations of designations. Astronomy historians comb through the logbooks of bygone observers to disentangle the target identification process. Even as this duo of galaxies appears to be interacting, NGC 4496A (the upper one of the pair) lies at a distance of 48 million light-years, much closer than its smaller companion, NGC 4496B, which is more than 200 million light-years distant.

Of Sweeps and Discoveries

The great German-born British astronomer William Herschel (1738–1822) discovered all the objects discussed here in but a few nights of observing using his renowned "sweeping" technique.

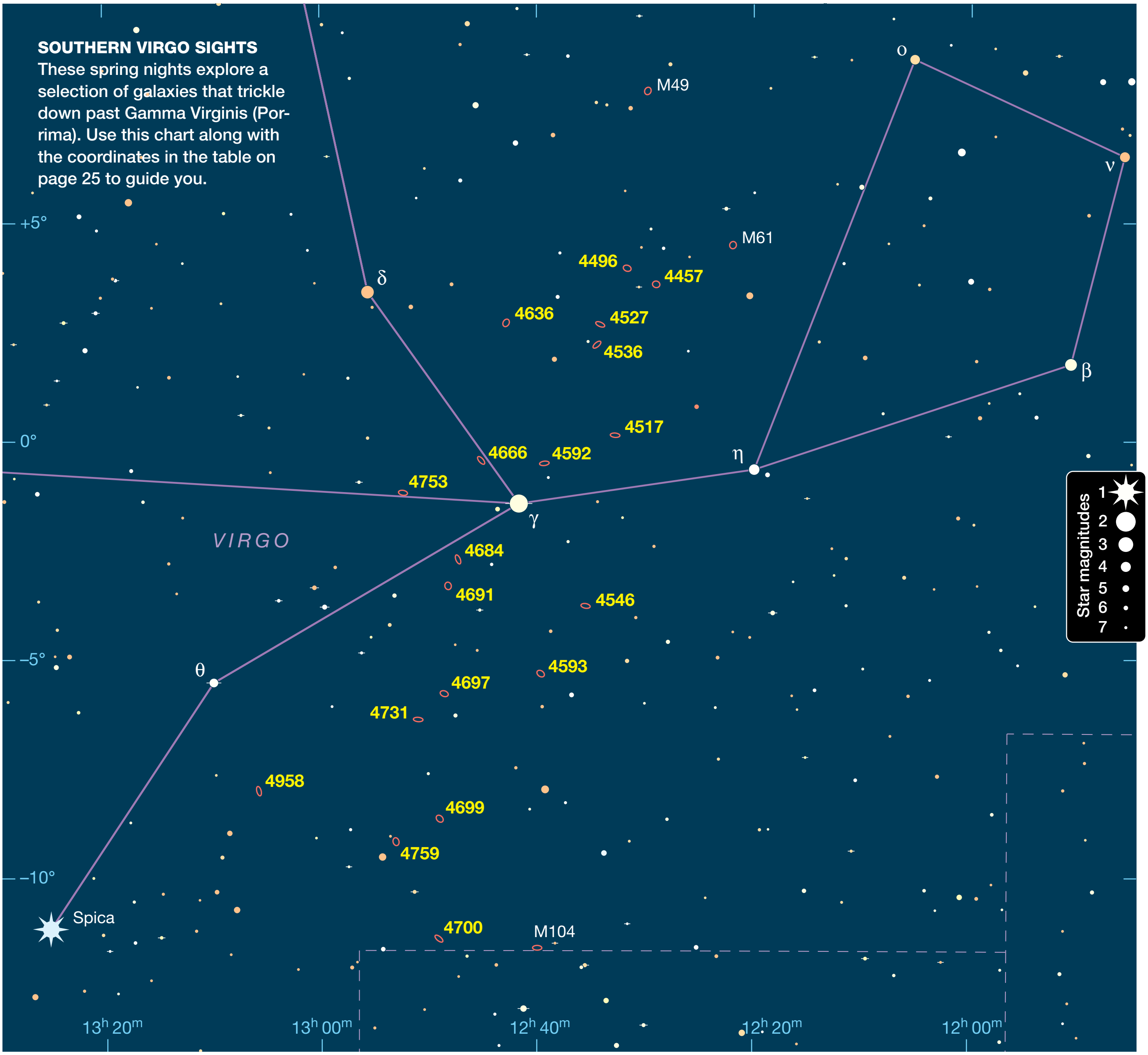
1784		1786
January 24	**April 22**	**March 3**
Sweep 120	*Sweep 204*	*Sweep 536*
NGC 4536	NGC 4684	NGC 4958
	NGC 4691	NGC 4699
February 22	**April 24**	**March 25**
Sweep 154	*Sweep 205*	*Sweep 546*
NGC 4517	NGC 4593	NGC 4759se
NGC 4592	NGC 4697	NGC 4759nw
NGC 4666		NGC 4700
February 23	**April 25**	**December 29**
Sweep 158	*Sweep 207*	*Sweep 674*
NGC 4496	NGC 4731	NGC 4546
NGC 4457		
NGC 4527		
NGC 4636		

NGC 4636 is an elliptical galaxy of magnitude 9.5 located 2.2° east of NGC 4527. William described it in his notes as pretty bright and pretty large but nevertheless listed it as Class II (Faint Nebulae) in his classification scheme. In my 10-inch Dob, it's bright and round with a prominent core, while my 18-inch shows a fainter, slightly elongated halo.

Poking Around the Middle

William placed **NGC 4517** in his Class IV (Planetary Nebulae). Corwin speculates that William classified it as such due to the supposed interaction with a nearby star (possibly the one sitting north of the galaxy; see the image on page 23). Corwin also suggests that this demonstrates that William's classification scheme wasn't yet fully developed at this point. Forty-four years after his father's discovery, John observed the object on April 14, 1828, and, due to a 5′ error in right ascension, his discovery was assigned the separate designation NGC 4437. There is no object at John's recorded position, and his description matches his father's perfectly.

NGC 4517 is a very large, 10.4-magnitude edge-on spiral located 3.6° southwest of NGC 4636. It has rather low surface brightness but is indeed impressive in the eyepiece. I noted a dust lane when viewing it with my 18-inch Dob. In a preliminary 2019 study, Korean researchers found that NGC 4517 and nearby **NGC 4592** comprise the core of a galaxy group that lies in front of the main Virgo Cluster at a distance of



around 29 million light-years. The galaxies, along with a number of dwarf galaxy companions, are infalling into the cluster.

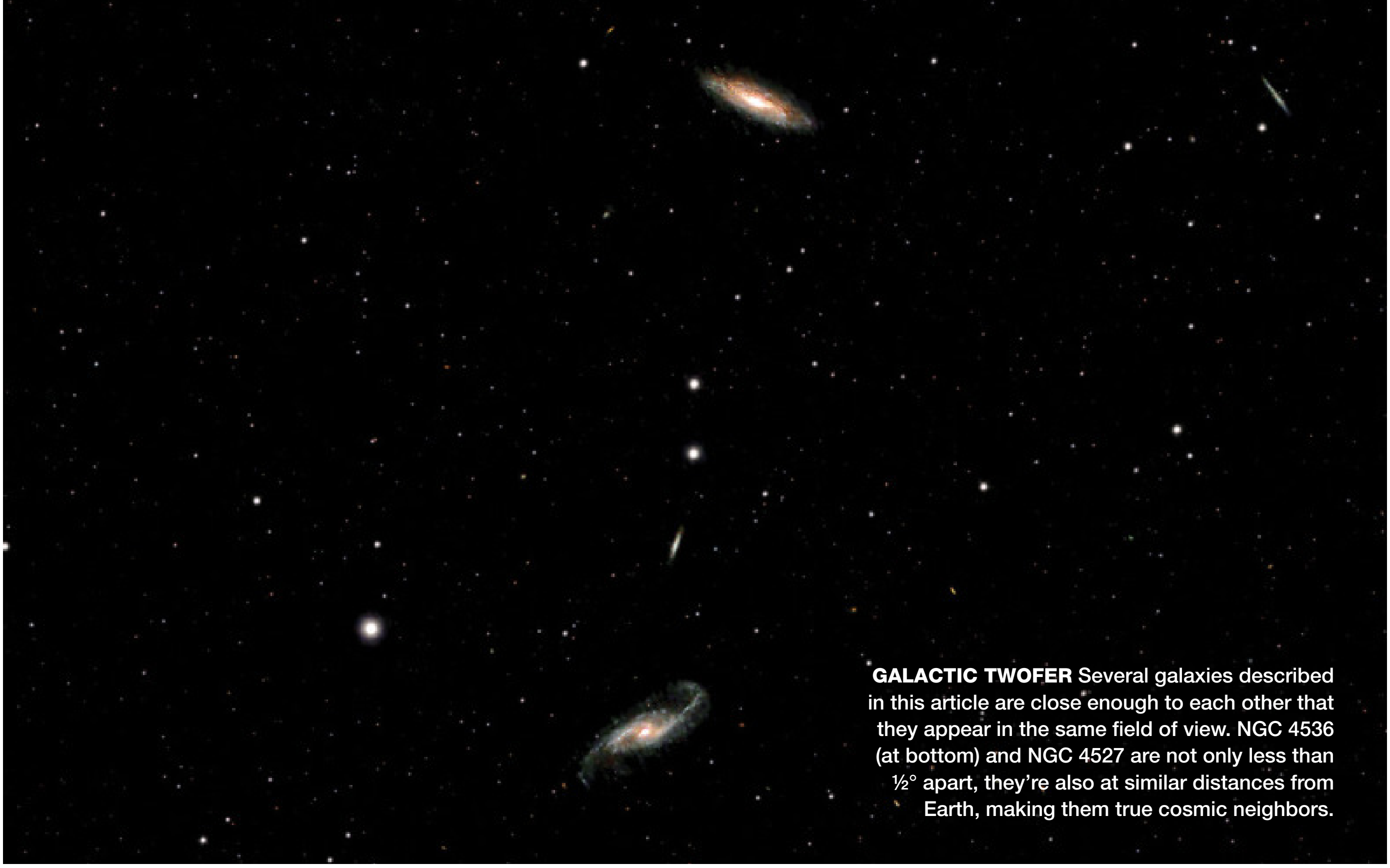
Look for NGC 4592, an 11.6-magnitude edge-on spiral with a brighter center, 1.8° east-southeast of NGC 4517. It's a convenient stop on our way to **NGC 4666**, the Superwind Galaxy, another 1.5° east.

NGC 4666 earns its nickname by virtue of being a starburst galaxy with a highly energetic superwind of outflowing gas that's visible in X-ray wavelengths. It's a very bright (magnitude 10.7), edge-on galaxy, that I see having a mottled, dusty appearance. William described it as "not cometic" (i.e., not comet-like) and similar to NGC 4592.

Before continuing southeast to our next target, it would be a shame not to make a slight detour to enjoy the lovely double star Gamma (γ) Virginis, or Porrima, which is almost 1⅓° to the southwest. The separation of the binary pair is currently about 3.3″, putting it within reach of a 3-inch telescope.

Getting back to the galaxies, **NGC 4753** lies 1.9° east-southeast of NGC 4666. William's discovery notes describe it as "a fine nebula, brightest in the M [middle]; pL [pretty large]; 4 or 5′ extent. It is not quite R [round], but a little compressed. The middle though vB [very bright] does not resemble the nucleus of a comet."

NGC 4753 is a large, bright (magnitude 9.9) oval with an intense core and a fainter, extended halo best viewed with averted vision. It's elongated east-west and classified as an irregular. Images show a complex dust lane that researchers propose is evidence of its disk being twisted by a process



GALACTIC TWOFER Several galaxies described in this article are close enough to each other that they appear in the same field of view. NGC 4536 (at bottom) and NGC 4527 are not only less than ½° apart, they're also at similar distances from Earth, making them true cosmic neighbors.

▲ **MILKY RAY** When William discovered NGC 4517 in February 1784, he described it as a "pretty bright star with a milky ray on the south side of it, extending from east to west . . . ." Powerful as it was for the time, his equipment couldn't quite discern the galaxy for what it was.

NGC 4536 AND NGC 4527: IAN STEPHENSON; NGC 4517: JERRY MACON

called *differential precession*. Investigations of the three-dimensional mass distribution of such disks may be useful tools for studying dark matter halos.

From NGC 4753, we hop 2° southwest to bring **NGC 4684** and **NGC 4691**, separated by 39′, together into the field of view of a medium-power eyepiece. NGC 4684 is an 11.4-magnitude, nearly edge-on spiral and may be barred (but the presence of a bar is not definitively established). This lens-shaped galaxy is elongated north-northeast to south-southwest and is brighter in the middle. NGC 4691, on the other hand, is an 11.1-magnitude barred spiral oriented nearly face-on and slightly elongated northeast to southwest — I see it as an oval with a much brighter core.

Now hopping 3.2° west-southwest of NGC 4691, we come to **NGC 4546**. This 10.3-magnitude spiral is nearly edge-on, and, as with NGC 4684, the presence of a bar is uncertain although suspected. In both galaxies there's evidence of counter-rotating molecular gas that orbits in a direction opposite to that of the stellar disk, which may be due to a previous collision with a dwarf galaxy.

Trickling Down to the Bottom

From NGC 4546 we move 1.9° southeast to reach **NGC 4593**, a lovely barred spiral of magnitude 10.9. It has a very bright core with a visible bar. In my 18-inch, I detect two faint arms that wrap around an oval halo, while in the 10-inch I only just suspect the presence of the arms. This *Seyfert galaxy* (active galaxies with quasarlike nuclei) contains a central black hole about 10 million times the mass of the Sun.

Look 2.3° east-southeast of NGC 4593 to find **NGC 4697**, a 9.2-magnitude elliptical galaxy that appears as a large

▲ **SUPERWINDS** The starburst galaxy NGC 4666 is in the throes of particularly intense episodes of star formation. Driving this activity is a *superwind* — a massive displacement of gas from the galaxy's core into intergalactic space. NGC 4666 might be interacting gravitationally with NGC 4668, the dwarf galaxy at lower left, which may possibly be triggering the starburst phase.

▲ **TWISTED DISK** NGC 4753 exhibits a curious series of crisscrossing dust lanes. Astronomers attribute this feature to a merger event, when the galaxy subsumed a smaller companion. The accreted material fashioned into a disk, and precession twisted the disk into the shape we see today.

GARY IMM (2)

bright ovate sprinkled with several stars. William wrote ". . . the brightness breaks off abruptly so as to almost resemble a resolvable nucleus consisting of 4 or 5 bright stars . . . ." An 11th-magnitude star lies 2.7' northeast of the core.

Continuing another 50′ southeast, we encounter the soft glow of the nearly edge-on barred spiral **NGC 4731**. Of magnitude 11.5, it's fairly large and elongated almost east-west. William described it as bright, but I find it to be rather faint, which instead agrees with John's description of the object. NGC 4731 is a member of the NGC 4697 group, which is a subcomponent of the Virgo II Groups. Photographs show twisted, extended arms that may be the result of gravitational interactions with a nearby galaxy.

Slewing 4° east-southeast of NGC 4731 we come to **NGC 4958**, a bright (magnitude 10.7), lens-shaped lenticular. It's classified as a barred galaxy, but the presence of a bar is not confirmed, nor is it apparent visually. NGC 4958 is elongated nearly exactly north-south and seemed impressively bright in my 18-inch Dob. A 2019 paper outlined evidence of an accretion disk around a supermassive black hole at its center, typical of an AGN.

Turning back and moving 4.2° west-southwest we come to another rather bright target. **NGC 4699** is a 9.5-magnitude spiral with a very prominent center seen at an intermediate orientation and elongated northeast-southwest. It resides about 64 million light-years from Earth. William recorded it as being "very brilliant." Observing it in my 18-inch Dob, I described it as a conspicuous oval with an abruptly brighter core.

The compact galaxy group Hickson 62 sits 1.1° east-southeast of NGC 4699 and comprises four members ranging in magnitude from 12.5 to 15.1. The main object of interest here is the double galaxy, which William first identified, but apparently did not see, as double. This Hickson group as a whole — and the double galaxy in particular — has a rather tortured history of misidentifications. (See page 57 for the Going Deep column on observing select Hickson Groups.)

Corwin explains that the double galaxy has three designations in the *NGC*. After William's original observation on March 25, 1786, he included it in his Faint Nebulae category, and the *NGC* later listed it as NGC 4759. When John observed the galaxy pair, he saw it as two objects and assigned it two different numbers in the *General Catalogue of Nebulae and Clusters of Stars*. John Louis Emil Dreyer, compiler of the *NGC*, assumed that John's pair was different from William's object and so listed them as NGC 4776 and NGC 4778.

Contributing Editor Steve Gottlieb's informative NGC/IC site explains further that German astronomer Heinrich Louis d'Arrest observed the object on March 30, 1867, with an 11-inch refractor at Copenhagen Observatory. Along with measuring an accurate position, he noted a 10th-magnitude star that lies 1.5′ to the south. D'Arrest, however, did not perceive it as double but rather saw it as a single nebulosity. Fellow German astronomer Wilhelm Tempel, who instead recognized the object as double, confirmed d'Arrest's position using Arcetri Observatory's 11-inch refractor.

The *Revised New Catalogue of Nonstellar Astronomical Objects* and the *Morphological Catalogue of Galaxies* identify the two components as NGC 4759 and NGC 4761. Corwin, however, has established that the galaxy that lies 1′ east-northeast of the southeastern component of the double, often identified as NGC 4764, is properly NGC 4761.

The double galaxy comprises the two brightest members of Hickson 62. The southeastern companion is the brighter component designated HCG 62A. This galaxy should instead

be identified as NGC 4778, which is also NGC 4759B. The northwestern component is therefore NGC 4776, or NGC 4759A. To avoid confusing the two, Corwin recommends using **NGC 4759se** and **NGC 4759nw**.

By any name, the pair can be hard to separate into discreet parts. Under the best conditions, the irregular-looking object will resolve into two bright cores that are almost in contact with a fainter common halo.

Our final stop is 2.7° south of NGC 4699. Twelfth-magnitude **NGC 4700** lies 2.2° east-northeast of our southern bracket, the Sombrero Galaxy (M104). I find this very thin edge-on spiral to be quite pleasing. It's angled northeast-southwest and is about five times longer than it is wide. My 30-inch Dob shows a thin dust lane, perpendicular to the long axis, that separates the southwestern third of the elongated streak. A 12th-magnitude star lies 2′ west. At a distance of 20 million light-years, it's the closest galaxy we've visited on this tour.

To the eye, galaxies seem little more than dim patches of nebulosity. To the mind's eye, however, they are truly objects of wonder. William Herschel discovered all the objects I've described here, but he didn't know their true nature. We can only imagine what flights of fancy Sir William may have attached to these *nebulae*, but we can be certain that he couldn't have even imagined the reality.

We, however, are quite privileged to have the benefit of today's knowledge, enabling our imaginations to soar to greater heights. We can enjoy a more informed speculation, grasp the enormity of these objects and the vast distances that separate us, and marvel at light that was emitted before *Homo sapiens* walked on Earth!

Employ your imagination as part of your observing routine, and you'll add a dimension that far surpasses the simple mechanics of detecting these faint targets with your telescope.

■ Contributing Editor **TED FORTE** ponders the nature of distant galaxies from his home observatory outside of Sierra Vista, Arizona.

HISTORY LINKS: You'll find Steve Gottlieb's and Harold Corwin's informative websites at **https://is.gd/astronomy_mall** and **haroldcorwin.net/ngcic**, respectively. Wolfgang Steinicke's website **https://is.gd/steinicke_ngc** also brims with historical detail.

Virgo Galaxy-Hop Targets

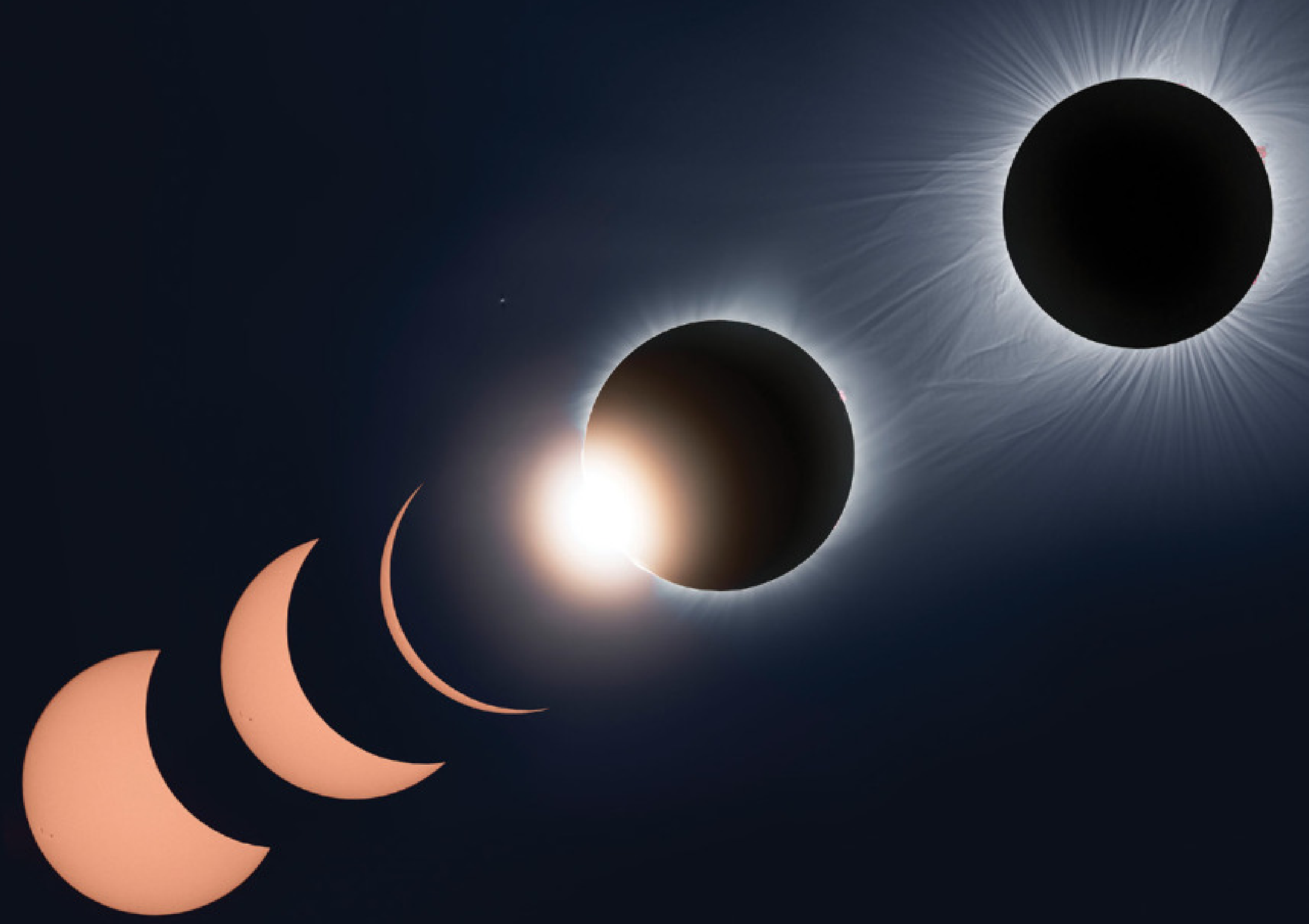
Object	Surface Brightness	Mag(v)	Size	Dist (Ml-y)	Difficulty	Magnif(×)	RA	Dec.
NGC 4496	14.0	11.4	4.0′ × 3.2′	48	3	120	12^h 31.7^m	+03° 56′
NGC 4457	12.7	10.9	2.7′ × 2.3′	63	2	120	12^h 29.0^m	+03° 34′
NGC 4527	13.2	10.5	6.2′ × 2.1′	44	3	120	12^h 34.1^m	+02° 39′
NGC 4536	13.9	10.6	7.6′ × 3.2′	47	3	120	12^h 34.5^m	+02° 11′
NGC 4636	13.1	9.5	6.0′ × 4.7′	4	2	120	12^h 42.8^m	+02° 41′
NGC 4517	13.2	10.4	10.5′ × 1.5′	29	3	120	12^h 32.8^m	+00° 07′
NGC 4592	13.8	11.6	5.8′ × 1.5′	38	3	120	12^h 39.3^m	–00° 32′
NGC 4666	12.5	10.7	4.6′ × 1.3′	51	3	120	12^h 45.1^m	–00° 28′
NGC 4753	12.9	9.9	6.0′ × 2.8′	79	2	120	12^h 52.4^m	–01° 12′
NGC 4684	12.4	11.4	2.9′ × 1.0′	45	3	120	12^h 47.3^m	–02° 44′
NGC 4691	13.0	11.1	2.8′ × 2.3′	65	2	120	12^h 48.2^m	–03° 20′
NGC 4546	11.9	10.3	3.3′ × 1.4′	46	2	120	12^h 35.5^m	–03° 48′
NGC 4593	13.4	10.9	3.9′ × 2.9′	125	3	120	12^h 39.7^m	–05° 21′
NGC 4697	13.0	9.2	7.2′ × 4.7′	41	2	120	12^h 48.6^m	–05° 48′
NGC 4731	14.9	11.5	6.6′ × 4.2′	42	3	120	12^h 51.0^m	–06° 23′
NGC 4958	12.3	10.7	4.1′ × 1.2′	48	3	120	13^h 05.8^m	–08° 01′
NGC 4699	11.9	9.5	3.8′ × 2.6′	64	2	120	12^h 49.0^m	–08° 40′
NGC 4759nw	12.7	13.0	0.9′ × 0.9′	167	4	80	12^h 53.1^m	–09° 12′
NGC 4759se	13.6	12.5	1.8′ × 1.8′	208	4	60	12^h 53.1^m	–09° 12′
NGC 4700	12.8	11.9	3.2′ × 0.8′	20	3	120	12^h 49.1^m	–11° 25′

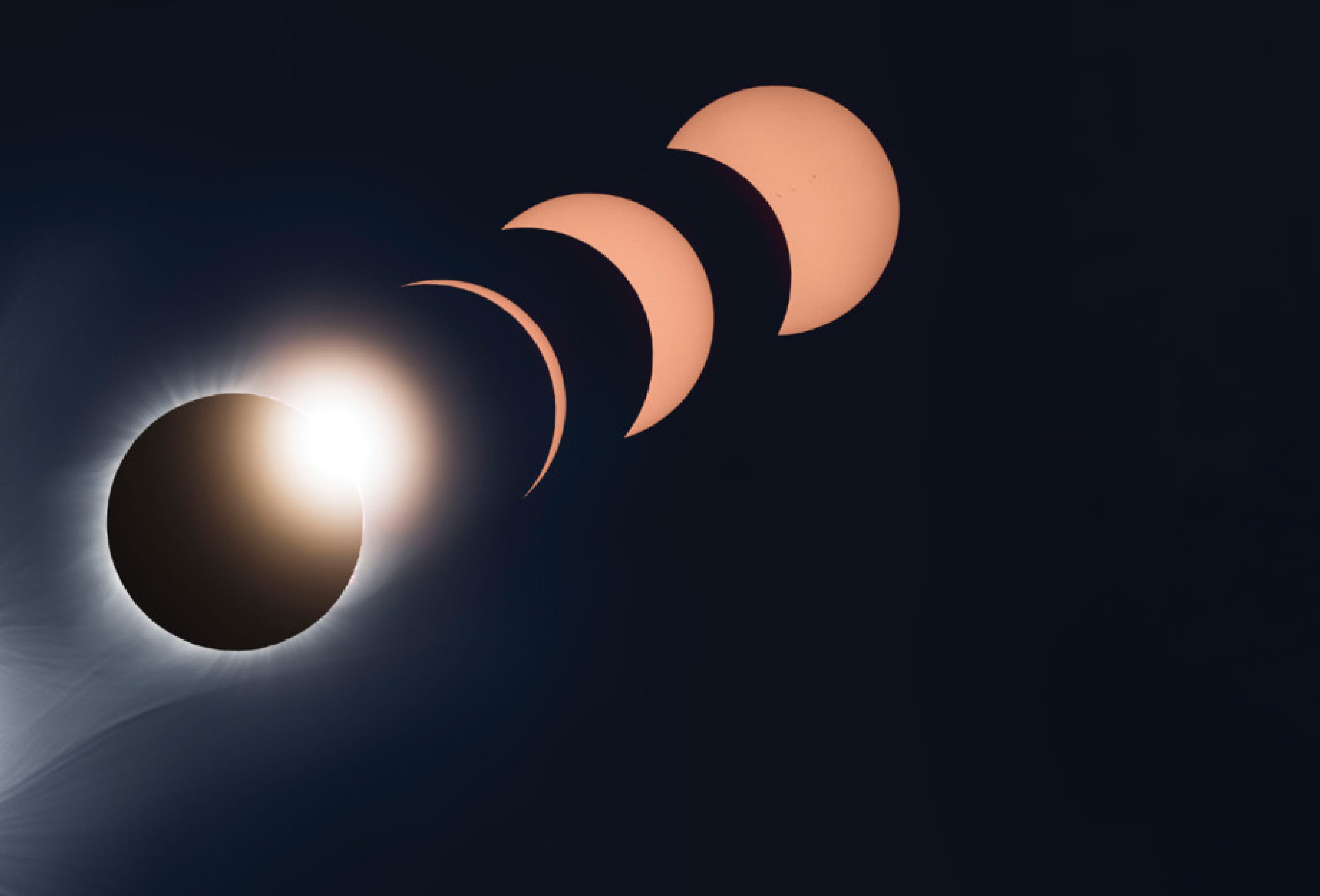
Angular sizes are from recent catalogs. Difficulty is based on a 10-inch telescope where 1 = obvious and 7 = not visible. Recommended magnification is based on a 10-inch aperture in dark skies. Note that NGC 4759nw and NGC 4759se are plotted as a single object on the finder chart. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

 by Fred Espenak and Jay Anderson

Get Ready for Totality in ’24

The Moon’s shadow sweeps across Mexico, the United States, and eastern Canada next year.





It seems like only yesterday that so many of us thrilled to the great American total solar eclipse of 2017. That event was the most watched eclipse of all time, with an estimated 216 million people experiencing it in person or online. Six years later it's time to start preparing for something of a replay of what is the most stunning and awe-inspiring naked-eye event in all of astronomy.

The total solar eclipse of April 8, 2024 will cross Mexico, the central and northeastern United States, and eastern Canada. Compared to 2017, this time the path of the Moon's shadow at greatest eclipse is wider, at 197.5 kilometers (122.7 miles) across versus 114.7 km, and the duration is nearly twice as long — up to 4 minutes 28 seconds, versus 2 minutes 40 seconds. With portions of 15 states and six Canadian provinces in the path, the 2024 eclipse promises to surpass the viewership achieved in 2017.

Excluding Alaska and Hawai'i, some 328 million Americans are within a two-day drive of the central path, and international interest is also keen. As a result, planning well ahead is necessary. Even now, accommodations at choice locations are beginning to fill up. To make your assessment easier, we have divided the eclipse path into several geographic regions and describe the circumstances and weather prospects for each one.

Unlike the August 2017 eclipse, this one lacks late-summer's promise of good viewing circumstances. The 2024 eclipse, with its sweep from subtropical to Arctic latitudes, encounters a full suite of potential conditions, from summer thunderstorms in the south to a wintry snowpack in the north. April is a month of changes, with a disorganized parade of low- and high-pressure systems marching across the continent, each one bringing clouds followed by bright sunshine in turn. Because the main spring storm track lies across the middle of the continent and passes south of the Great Lakes, states and provinces lying in the shadow path's northern reaches have much cloudier weather than those to the south.

▲ **THE GREAT 2017 ECLIPSE** Fantastic photos like this one are cherished reminders of the recent American eclipse. This sequence captures the event's highlights, including totality and the diamond-ring effect seen just before and after totality. If the weather cooperates, millions across North America will witness this grand spectacle on April 8, 2024.

FRED ESPENAK

In general, sunnier weather comes with warmer temperatures. As a result, selecting the best viewing location can be as simple as heading south, where the warm season is most advanced. Climatology points the determined eclipsophile to Mexico, where spring is well underway.

Mexico

The Moon's umbral shadow first touches Earth at 16:40 UT in the South Pacific, about 3,300 km south of the Hawaiian Islands and 1,390 km northwest of Tahiti. Along the sunrise terminator, the maximum duration of totality is $2^m\ 6^s$ as seen from the center of the 143-km-wide path. No major landfall occurs during the first 85 minutes of the eclipse as the shadow sweeps northeast across the Pacific.

The umbra finally meets terra firma on Mexico's Islas Marías at 18:05 UT (11:05 MST). This archipelago lies about 100 km off the country's west coast. Isla María Madre is completely inside the path of totality, while Isla María Magdalena is bisected by its southern limit. Five minutes later (18:10 UT; 11:10 MST), the umbra reaches Mexico's Pacific Coast in the state of Nayarit.

The central line duration of totality here is $4^m\ 27^s$, and the Sun stands 69° above the horizon. The path width has expanded to 199 km as the shadow pursues its eastward track, with a ground velocity of 0.70 km/second — twice the speed of sound.

Mazatlán, a major resort city known for its beaches and sunny weather, is 26 km northwest of the central line. Visitors and the city's population of 500,000 will experience $4^m\ 16^s$ of totality. Many eclipse chasers will be attracted by the long duration and promising weather prospects of this destination.

After crossing a relatively narrow, 25-km-wide coastal plain, the path climbs over the Sierra Madre Occidental mountain range (2,600 m, or 8,500 ft elevation) and enters the desert plains and low mountain ridges of the Mexican Plateau (1,100 m). Durango lies about 55 km south of the central line but still manages $3^m\ 47^s$ of totality.

The umbra reaches the point of *greatest eclipse* (the instant when the axis of the Moon's shadow passes closest to the center of Earth) at 18:17:20 UT (12:17:20 CST) about 150 km northeast of the city of Durango. At that moment the Sun's altitude is 70°, the duration of totality is $4^m\ 28^s$, and the path of totality is 197.5 km wide. Although the ground speed of the shadow is near its minimum, it's still twice the speed of sound. The theoretical point of the *greatest duration* (the maximum amount of totality) is another 95 km to the northeast but only exceeds the duration of greatest eclipse by 0.05 seconds.

Climbing over the Sierra Madre Oriental range (1,500 m elevation on the eclipse path), the lunar shadow descends into the lowlands of the Gulf Coastal Plain. The city of Piedras Negras stands on the southern side of the Rio Bravo (the Rio Grande, as the river is called on the American side of the border) 14 km southeast of the central line, where totality lasts $4^m\ 24^s$.

From a meteorological perspective, your best options are along the coast near Mazatlán, inland on the high plateau around Durango or Torreón, or toward the U.S. border near Zaragoza. The coast and plateau have similar meteorological histories, with monthly cloud-cover amounts averaging around 25% to 30%. Both are subject to mid- and high-level cloudiness associated with the subtropical jet stream; such cloudiness is perhaps a little more frequent on the Pacific coast. Mazatlán has to deal with the occasional morning fog, though it should burn off before the time of the eclipse. More troublesome on the plateau are the occasional days with thunderstorms, which tend to form on the western mountains and spread cloud over the eclipse track, though most of this should come after the Moon's shadow has passed. The

▼ **MAXING OUT** This panoramic photo shows a view across Mexico's high plateau north of Torreón, looking toward the central line. The image was captured on April 7, 2022, from a location 120 km northeast of the point of maximum eclipse.

JAY ANDERSON

occasional cold front that sweeps southward out of Texas brings considerable cloudiness to the plateau but doesn't cross the mountains to reach Mazatlán.

Beyond Torreón, the eclipse track rises over the eastern Sierra Madres and descends onto the Gulf Coast lowlands, reaching the Rio Grande and the Texas border. Here, we encounter a new menace: fog and low cloud that move inland from the Gulf of Mexico, sometimes flooding the low-lying landscape far enough inland to cover the entire eclipse track. Satellite observations show that the average monthly cloudiness more than doubles between Torreón and Piedras Negras, to just under 50%.

Texas, Oklahoma, and Arkansas

The umbral shadow fords the Rio Grande and enters Texas at 18:30 UT (13:30 CDT). Although the central duration is beginning to decrease, it still clocks in at a generous $4^{m}\ 27^{s}$.

The eclipse track crosses Texas diagonally from the southwest to the northeast. Among the larger cities in the path are San Antonio (on the southern limit), Austin ($1^{m}\ 43^{s}$), Waco ($4^{m}\ 12^{s}$), Dallas ($3^{m}\ 51^{s}$), Fort Worth ($2^{m}\ 32^{s}$), and Texarkana ($2^{m}\ 22^{s}$). Houston, the largest city in Texas, is located 200 km outside the path and experiences a partial eclipse in which the Moon covers 94.3% of the Sun's diameter.

Approximately 12.8 million people live in the eclipse path through Texas. In comparison, the population living within the entire path through the U.S. is approximately 31.8 million.

Leaving the Lone Star State, the lunar shadow cuts across the southeastern corner of Oklahoma. Broken Bow lies 14 km north of the central line and can expect $4^{m}\ 17^{s}$ of totality. Approximately half of Arkansas lies within the path, including the capital city of Little Rock, which is located within 18 km of the path's southern limit. The city will experience a total eclipse lasting $2^{m}\ 26^{s}$.

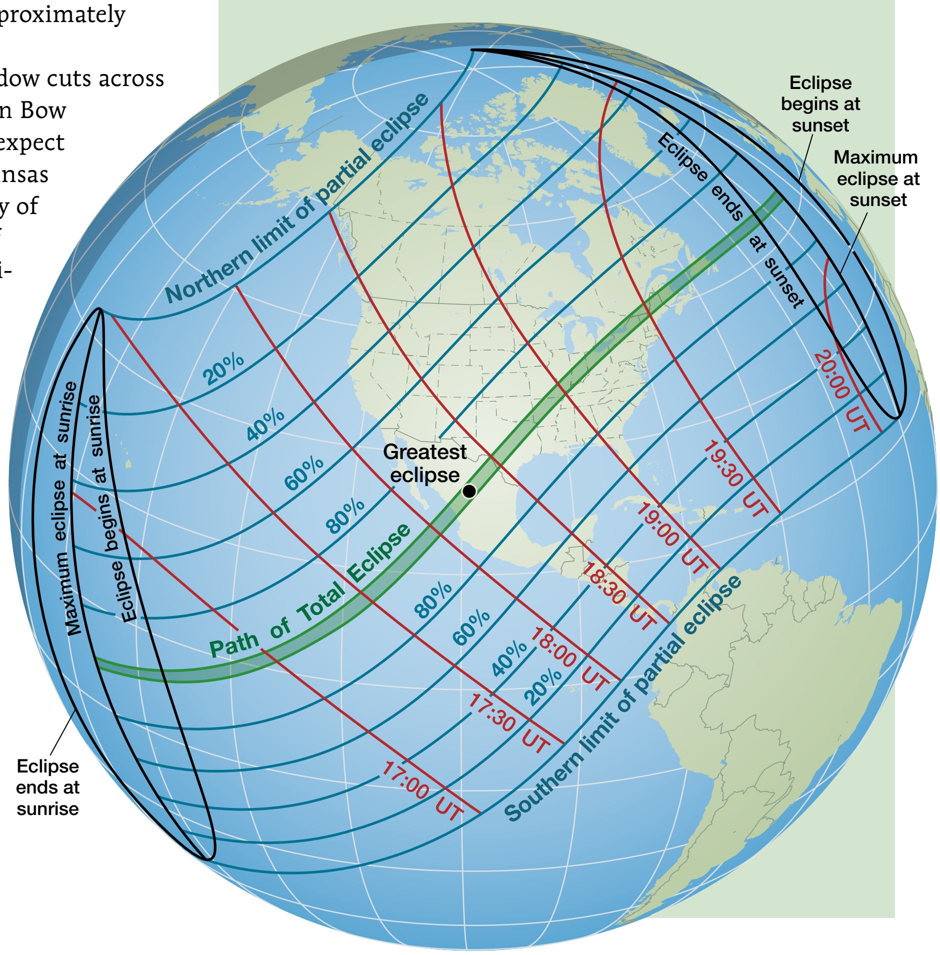
Within the U.S., Texas weather offers the best clear-sky prospects for the event, according to cloud-cover records of the past 22 years. Even so, Lone Star State prospects are not particularly enticing — satellite observations show an average cloudiness of around 45% near the Mexico border and 55% at the Oklahoma/Arkansas line.

Aside from the usual cold fronts coming from the north and jet-stream cloud from the southwest, this region also has to contend with moisture invading from the Gulf of Mexico. South or southeasterly winds carry Gulf moisture onto the coastal plains, flowing across low elevations onto the eclipse track. Large sheets of stratus cloud may form overnight and may or may not break up into afternoon cumulus clouds when the Sun returns the next day. If Gulf moisture arrives as a shallow layer with light winds, stratus clouds

Eclipse-Planning Essentials

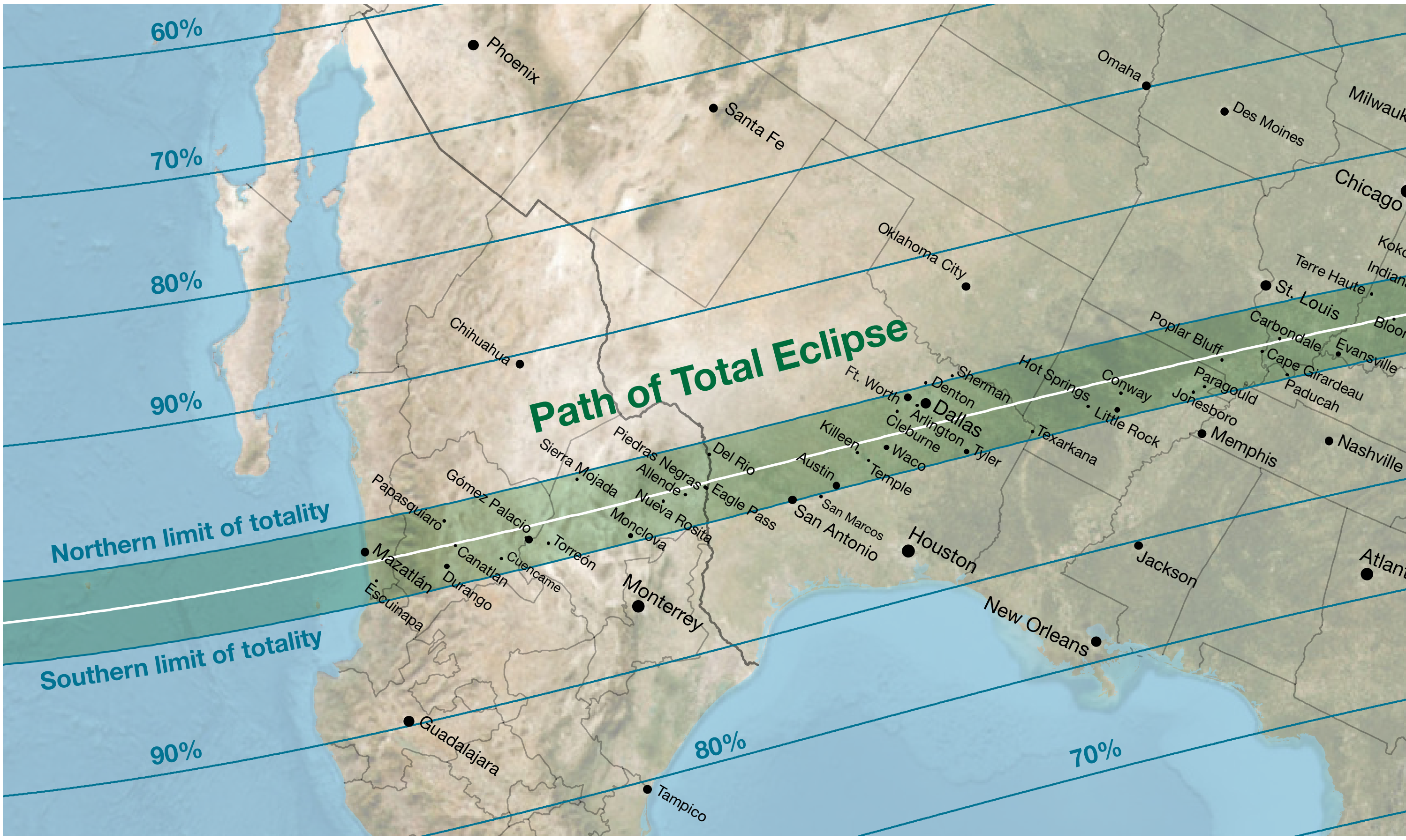
Authors Fred Espenak and Jay Anderson have collaborated on many eclipse-related publications for nearly 30 years. Now retired, they've reunited to publish *Eclipse Bulletin: Total Solar Eclipse of 2024 April 08*. It's filled with tables, charts, maps, weather data, and eclipse circumstances for hundreds of cities. Go to **eclipsewise.com/pubs/EB2024.html** for more information.

Separately, Espenak has published *Road Atlas for the Total Solar Eclipse of 2024*, a book of detailed road maps covering the entire path from Mexico to Newfoundland. The track is plotted in 30-second steps, making it easy to estimate the duration of totality from any location along the eclipse path. For details, visit **eclipsewise.com/pubs/Atlas2024.html**.



▶ **FROM THE PACIFIC TO THE ATLANTIC** Over the April 8, 2024 eclipse's total duration of 3 hours 15 minutes, the Moon's shadow travels along a 14,800-km (9,200-mi) strip that extends from the Pacific to the Atlantic. The percentage lines refer to the *eclipse magnitude*, which is the fraction of the Sun's diameter covered by the Moon.

S&T ILLUSTRATION, SOURCE: FRED ESPENAK



may barely reach San Antonio, blocked by the rising terrain along the Balcones Escarpment (better known as Texas Hill Country). On days with deep and persistent flows of moisture, stratus clouds will spread across the eclipse track, reaching far to the west on the Edwards Plateau and northward across the coastal plains beyond Waco and Dallas into Oklahoma and Arkansas.

The best weather in Texas is most likely to be found where the eclipse track crosses the highest elevations. Measurements of cloud cover from orbit give San Antonio an average cloud cover of 56% in April, while Junction and Brady, in the Hill Country near the western limit, record about 10% less. Unfortunately, these latter two communities have relatively short eclipse durations. From Waco to the Oklahoma border, average cloud cover hovers around 55%, with little to recommend one site over another. Texas-based eclipse chasers should plan to set up near the central line or farther westward along the Balcones Escarpment, avoiding the eastern side of the eclipse track.

Missouri, Tennessee, Illinois, Indiana, and Kentucky

The southeastern corner of Missouri, including Poplar Bluff, falls within the totality track. This "Gateway to the Ozarks" city will receive $4^{m}\,8^{s}$ of totality. Nearby and along the path's southern limit in Missouri, a meander in the Mississippi River brings a small point bar into the path. This tiny piece of land is the only part of Tennessee to experience totality.

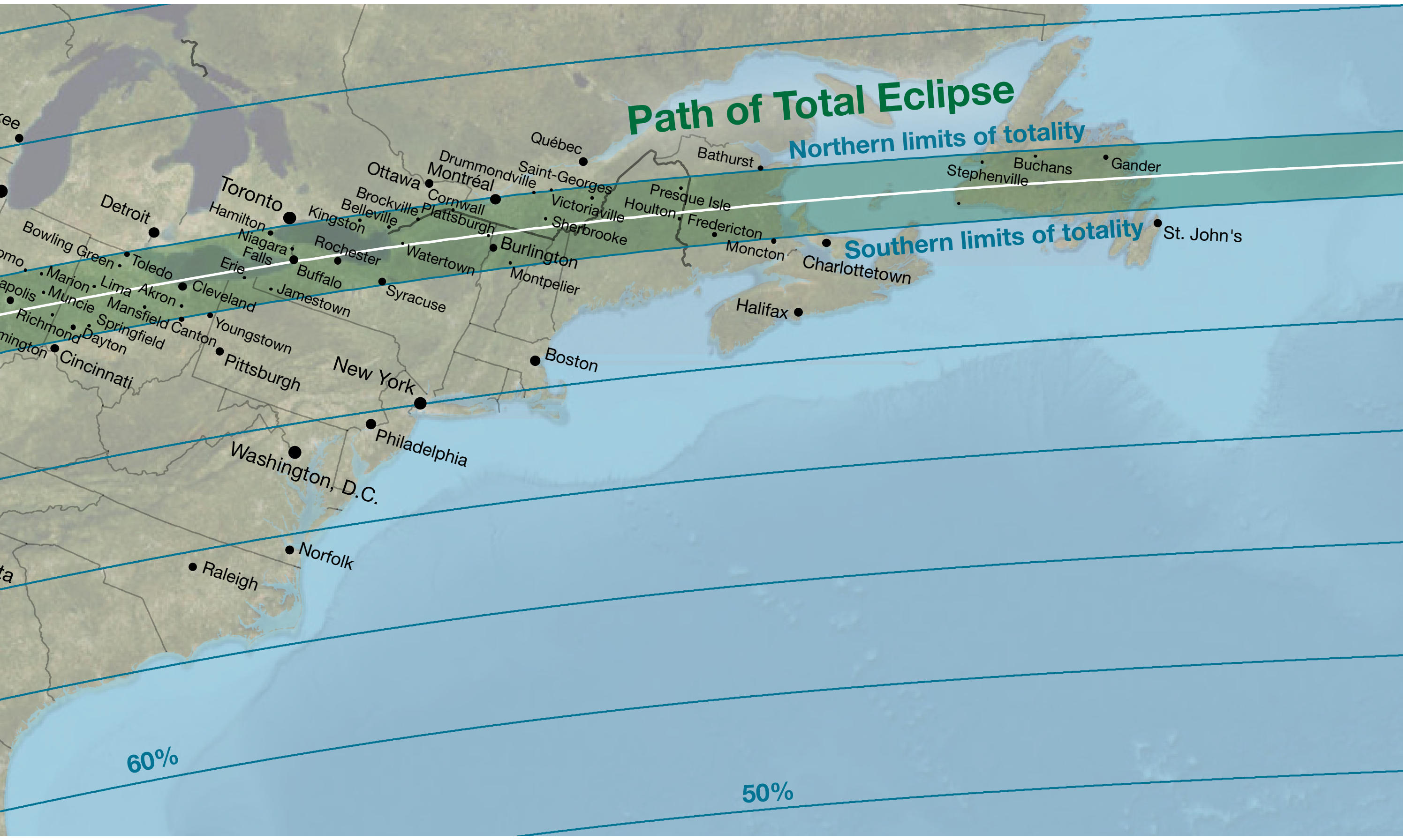
Cape Girardeau is Missouri's largest city in the path and will be in the Moon's umbral shadow for $4^{m}\,6^{s}$. The central line crosses the Missouri/Illinois border at approximately 19:00 UT (14:00 CDT). The path width is 186 km, the central duration is $4^{m}\,10^{s}$, and the Sun's altitude is 57°. Carbondale, Illinois, gets its second total solar eclipse in less than seven years. If the city's name is familiar to you, it's probably because it was a major destination in August 2017 thanks to its position near the point of greatest eclipse. This time it experiences $4^{m}\,8^{s}$ of totality.

The southern half of Indiana, including Indianapolis, stands in the umbra's path. Residents of the Hoosier State's capital will be engulfed by the Moon's shadow for $3^{m}\,48^{s}$. It narrowly misses several large cities nearby, including Memphis, Tennessee (97.6%); St. Louis, Missouri (98.7%); and Louisville, Kentucky (98.9%).

To the southeast, the path grazes the western edge of Kentucky along the Mississippi border. The Bluegrass State's largest town in the path is Paducah, where totality lasts $1^{m}\,35^{s}$.

Along the eclipse path in this region, large weather systems become more and more important. Weather becomes less local and more regional, and differences in cloud cover from one location to the next are muted. The influence of terrain grows as the shadow heads northward, but through

MICHAEL ZEILER



Oklahoma, Arkansas, and Missouri, cloud cover along the central line is relatively constant, hanging around 55% to 60%, with one exception.

Beyond Little Rock, Arkansas, the eastern edge of the shadow moves over the lowlands of the Mississippi Alluvial Plain while the western side rests on the higher terrain of the Boston Mountains and the Ozark Plateau — a difference in elevation of nearly 600 m. The floodplain of the Mississippi is a reservoir of moisture that can hide under heavy layers of stratus and stratocumulus, pushing the cloud-cover statistics upward by about 15% from Little Rock to Cape Girardeau, Missouri. The high ground on the western side of the track is not particularly sunny either, so eclipse planners should probably opt for the central line and avoid sites from Jonesboro, Arkansas, to Kennett, Missouri, and onward to the confluence of the Ohio and Mississippi Rivers at Cairo, Illinois.

Ohio, Michigan, Pennsylvania, New York, and into Canada

The trajectory of the Moon's shadow through Ohio takes it across Toledo, Cleveland, and Akron. Three other Buckeye State cities, Cincinnati (99.4%), Columbus (99.6%), and Youngstown (99.7%), are near misses.

The southeastern corner of Michigan barely makes it into the eclipse path with a triangular wedge of land bordered by Ohio and Lake Erie. Unfortunately, nearby Detroit misses out but gets a deep partial eclipse of 99.1%. The central line crosses Lake Erie and clips the northwestern corner of Pennsylvania. The largest Keystone State city in the path is Erie, where totality lasts $3^m 42^s$.

▲ **FOLLOW THE MOON'S SHADOW** Eclipse chasers have a lot of geography to choose from as the Moon's shadow races across Mexico, the U.S., and through eastern Canada. While the eclipse central line may pass close to home for many observers, weather prospects along the path of totality vary widely, with regions in Mexico and Texas being the most favorable. The percentage lines refer to *eclipse obscuration*, which is the fraction of the Sun's area covered by the Moon.

Meanwhile, the northern edge of the path crosses the border into Ontario, Canada. The city of Hamilton stands 10 km inside the northern limit and receives $1^m 43^s$ of totality. Deeper in the path, St. Catharines residents get $3^m 16^s$ of total eclipse. Unfortunately, Ontario's capital city, Toronto, lies 9 km outside the path, thereby missing totality with a 99.7% partial at 19:20 UT (15:20 EDT).

Buffalo, New York, is on the central line, bringing it $3^m 45^s$ of totality. The path here is 179 km wide, and the Sun's altitude is 46°. About 32 km north of Buffalo is world-renowned Niagara Falls, where totality lasts $3^m 31^s$. Rochester stands on the southern shore of Lake Ontario, where eclipse watchers will experience $3^m 39^s$ of totality. Downtown Syracuse is within 7.5 km of the southern limit but still gets a total eclipse lasting $1^m 25^s$. In Canada, the path now runs across

southern Quebec. The northern edge of the eclipse path cuts across the province's largest city, Montreal, while totality lasts $3^m 24^s$ in Sherbrooke, to the east.

The weather story past Carbondale and into central Ohio is one of increasing cloudiness, with percentages rising from the upper 50s to the mid-70s before settling back into the high 60s through Pennsylvania and New York State. It sounds (and *is*) discouraging, but a new influence comes into play where the track crosses the Great Lakes. It's not terrain this time but the presence of the Lakes themselves.

As the path reaches Lake Erie, cloudiness on the central line declines sharply, falling to under 60% at Cleveland, Ohio, and nearly as much at Erie, Pennsylvania, and Dunkirk, New York. The effect is found only on the southern shores of the lakes, showing that the beneficial effect on cloud cover comes with northerly winds. The northern limit of the track, on the Canadian side of the lakes, does not benefit from the lee-side clearing except downwind from Lake St. Clair, near Leamington, Ontario. On the opposite side of the track, the southern limit is too far from the lake to feel its effects.

The same lake influence can be found along the southern shores of Lake Ontario as well, along an arc from Niagara Falls past Rochester and Oswego almost to Watertown, New York. Northern and southern limits, away from the lake's influence, show almost no change, lingering at 70% cloud cover. Canadian eclipse sites, near the northern limit, are on the wrong side of Lake Ontario and do not profit from its influence, though the portion of the path from Belleville to Kingston has slightly better conditions than elsewhere, with average values of just over 60%.

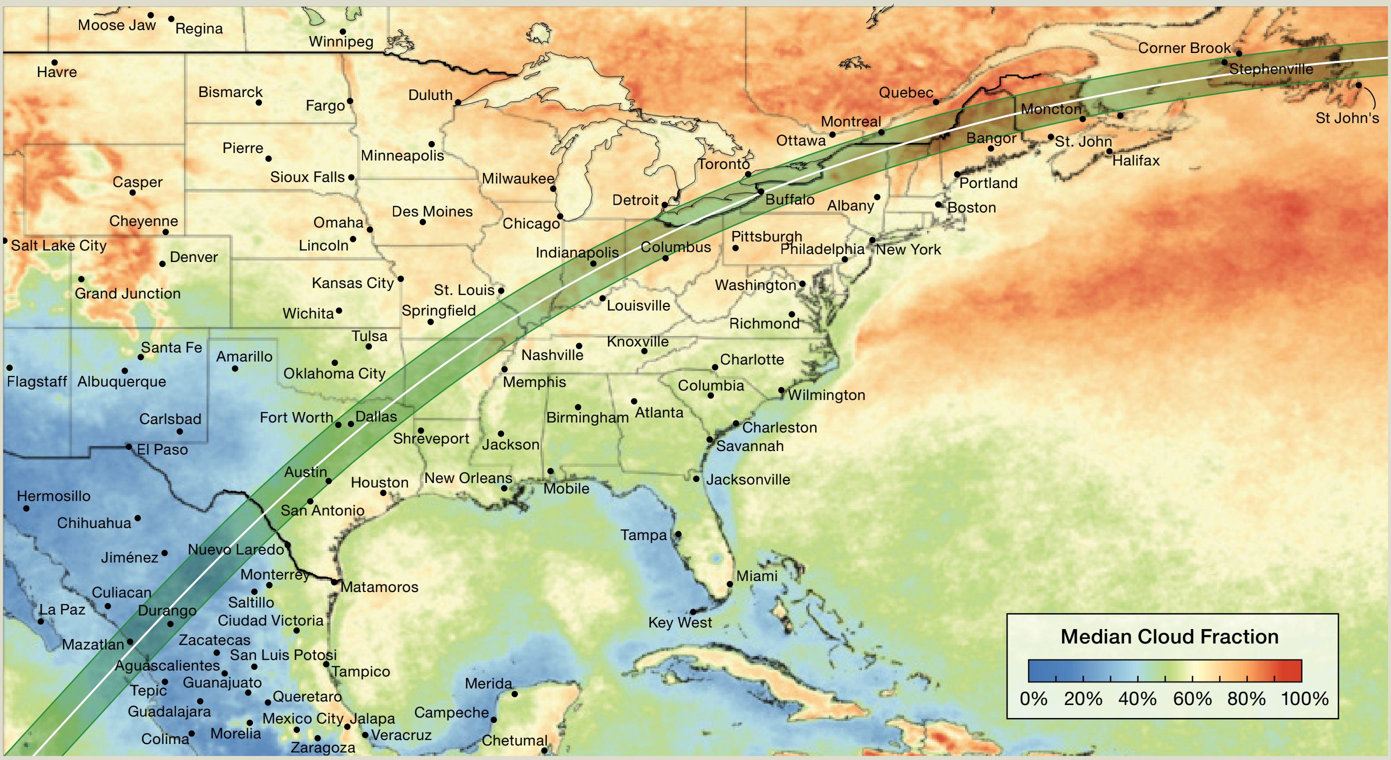
Beyond the Great Lakes, the Moon's shadow bounces over the northern limits of the Appalachian Mountains, with each upward bounce producing an increase in cloud cover and every valley a slight decrease. Cloud averages reach nearly 80% over New York's Adirondack Mountains on both the central line and the southern limit. On the northern edge of the track, the lowlands along the St. Lawrence River have less cloud cover, running in the 65% to 70% range, with both sides of the border sharing the benefit.

Northern New England and Atlantic Canada

Burlington, the most populous city in Vermont, is located 35 km south of the central line and enjoys $3^m 14^s$ of totality. Montpelier, the state capital, is within 12 km of the southern limit and sees a duration of $1^m 40^s$.

The path continues across northern New Hampshire and Maine, both of which are rural, with no sizable cities. Caribou, Maine, lies within 16 km of the path's northern limit and gets $2^m 10^s$ of totality. Located 65 km south of the path, Maine's capital city, Augusta, sees a 98.0% partial eclipse.

Exiting the United States, the remainder of the eclipse track runs solely through Canada. The path crosses central New Brunswick, where Fredericton, the provincial capital, lies 27 km from the southern limit and receives $2^m 14^s$ of totality. Moncton, the largest city in the province, is just



JAY ANDERSON, DATA SOURCE: NASA

outside the eclipse path but gets a very deep partial of 99.8%. The path width across New Brunswick is 170 km, and the Sun's altitude is 34°.

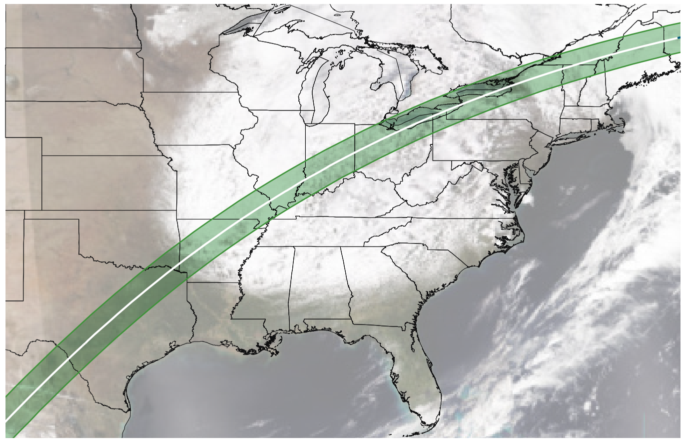
Western Prince Edward Island lies within the zone of totality, but Charlottetown misses; observers there will have to settle for a 99.2% partial. Quebec's Magdalen Islands straddle the central line, and the shadow track also clips the northeastern tip of Nova Scotia's Cape Breton Island.

The final landfall for the umbral shadow is on the island of Newfoundland. There, the late-afternoon Sun is only 24° above the horizon, the eclipse duration at the central line is $2^m\ 54^s$, and the path width is 162 km. St. John's, the capital, is 42 km south of the umbral path. The city will get a deep partial eclipse, with 98.8% of the Sun's diameter covered by the Moon.

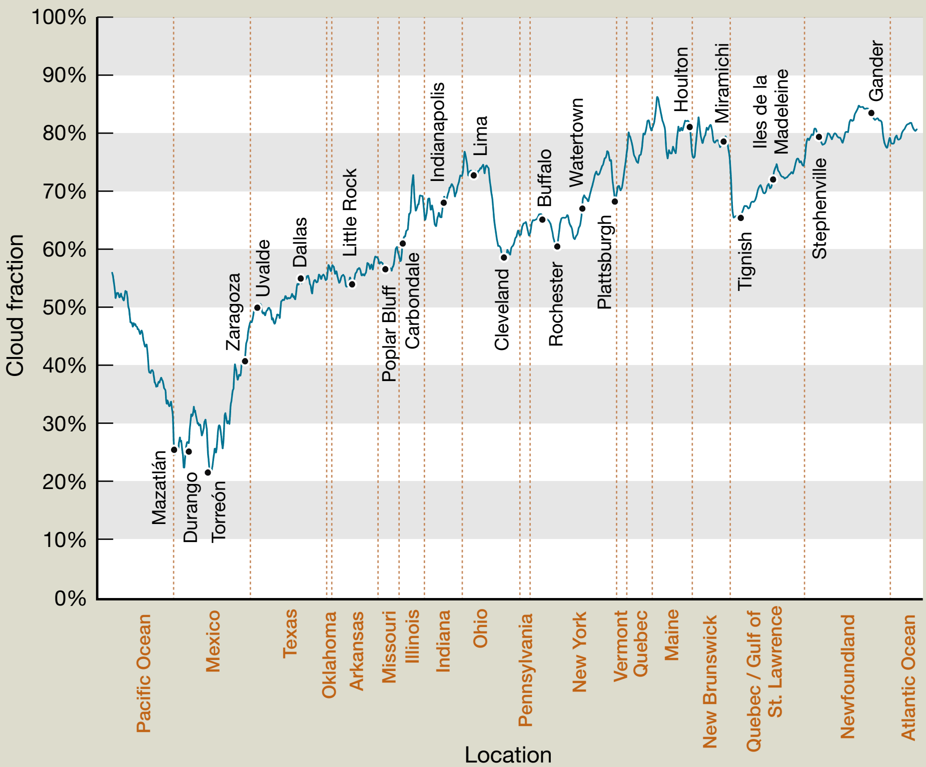
Mother Nature dealt New Hampshire, Vermont, Maine, and New Brunswick a lousy hand when it comes to weather prospects for this eclipse. The Moon's shadow crosses a series of terrain landmarks that spell out cloudiness: the Green Mountains of Vermont, the White Mountains of New Hampshire and Maine, the Longfellow Mountains of Maine, and the Miramachi Highlands in New Brunswick. Cloud cover is least on the New York-Vermont border, where the track passes the Champlain Valley and the St. Lawrence Lowlands.

Monthly cloud cover rises from around 68% at Montreal, Quebec, and Plattsburgh, New York, to nearly 90% at Jackman, Maine, before settling back to 80% for the rest of the passage to the Gulf of St. Lawrence. Cloudiness has little variation across the track, and terrain influences are muted because of the high natural cloudiness of the region arising from its position astride the season's main storm tracks.

The bright light in this gloomy scenario comes along New Brunswick's shoreline, where the track reaches the Gulf of St. Lawrence. As with the Great Lakes, water suppresses the formation of convective clouds — an effect that extends for a short distance inland when winds come from the north.



▲ **THE VIEW FROM ABOVE** This photograph, acquired from NASA's NOAA-20 satellite, shows the cloud cover along the eclipse track on April 8, 2022. At the time of this image, the eclipse shadow would lie over the Great Lakes. The discontinuity in the scene that stretches over Lake Ontario is caused by incorporating an earlier satellite passage into the view.

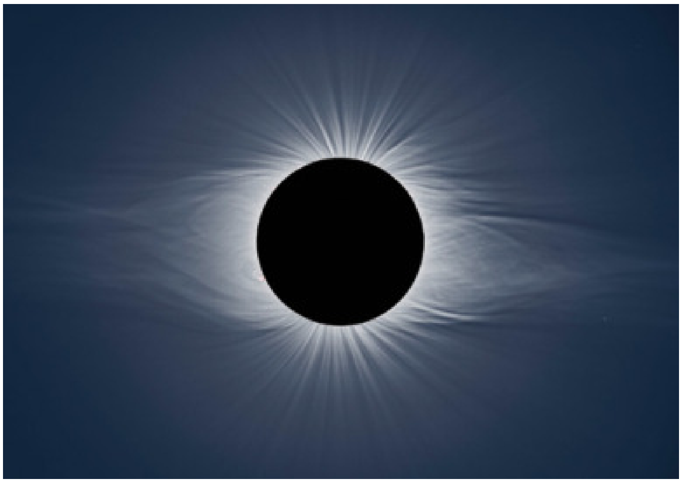


◀◀ **CLEARINGS AND CLOUDS** This map of average April cloud cover along the eclipse path is derived from 21 years of daily satellite imagery. Amounts are expressed in fractional sky cover and represent the amount of time the sky was cloudy in the two-decade interval.

◀ **ECLIPSE UPS AND DOWNS** The April fractional cloud amount along the central line of the eclipse is displayed graphically at left. It was derived from the same 21-year dataset as the map at far left. In many locations, the cloud statistics away from the central axis are quite different.

SATELLITE IMAGE: JAY ANDERSON; GRAPH: JAY ANDERSON, DATA SOURCE: NASA

FRED ESPENAK



▲ **CHILEAN ECLIPSE CROWN** The solar corona is only visible for a few, brief minutes during a total eclipse of the Sun. Because the corona encompasses an enormous range of brightness (the innermost corona is over 1,000 times brighter than the outer corona), it is difficult to photograph what the eye can see. This composite of 72 separate exposures has been processed to reveal and emphasize the fine structure present in the solar corona during the total solar eclipse of July 2, 2019.

▲ **DIAMOND RING** In the final seconds before totality, the shrinking crescent Sun produces a short, brilliant segment along one edge of the Moon known as the diamond ring. As the solar corona emerges into view in the rapidly darkening sky, the diamond grows smaller and breaks up into a string of bright points called Baily's Beads, which vanish as totality begins.

It's a very restricted impact but dramatic: April cloudiness drops from 80% to 65% as the central line crosses the shore. Prince Edward Island's North Cape protrudes into the eclipse shadow almost to the central line, giving the town of Tignish (3^m 11^s totality) the distinction of being the most promising observing spot between Vermont and the end of the eclipse path in the North Atlantic.

Alas, sunny weather is very hard to come by, and winter is very much still in evidence in Newfoundland. Measurements from weather stations show that a hopeful 30% to 35% of April daylight hours are sunny, but weather satellites indicate that skies are cloudy more than 80% of the month. Climate statistics show average snowfalls of 15 to 40 cm (6 to 16 in) in April, with precipitation occurring on half of the days. To extract the most that the area's climate can offer, determined eclipse seekers should travel to Cape Bonavista, the last bit of land under the shadow, where totality endures for 2^m 54^s.

Leaving Canada at a velocity of 2.08 km/s, the umbra races 2,450 km across the North Atlantic before slipping off our planet and returning to space.

An Eclipse for Everyone

Over the eclipse's total duration of 3 hours 15 minutes, the umbra travels along a 14,800-km strip that covers an area representing just 0.52% of Earth's surface. Even a year out, excitement is building for the 2024 eclipse. This is due in large part to the 2017 event, which introduced millions of people to the grandeur of totality.

It's a signature of the various climatologies crossed by this eclipse that watchers from Texas to Ohio may have to contend with severe-weather-producing thunderstorms, while those from Ohio to Newfoundland may encounter snowstorms and even late-season blizzards. With such a variety of possible weather constraints, you should turn to the forecasts for help with any last-minute decisions. You'll find that information is readily available on the internet, and that predictions reliable enough for serious decision-making can be had a week in advance.

Weather permitting, everyone in North America (except most of Alaska) will see something grand on eclipse day — even those outside the zone of totality. Looking up from Los Angeles at mid-eclipse — using safe viewing techniques, of course — you'll see 58% of the solar disk's diameter covered by the Moon. From New York City, it will be 91%. The partially eclipsed Sun will be worth viewing even from such widely separated locations as Honolulu, Hawai'i (28%); Vancouver, British Columbia (28%); and Miami, Florida (56%).

A total solar eclipse is not only a grand visual spectacle, but it's also a chance to convince family, friends, and neighbors that astronomy isn't just for astronomers. And maybe, just maybe, the 2024 eclipse might inspire some child to become the next Galileo, Newton, or Einstein!

◀ **2017 ECLIPSE FROM CASPER, WYOMING** This photo is a combination of images shot with two separate cameras. The first camera captured the partial phases through a solar filter at 5-minute intervals. A second camera had no solar filter and was used to photograph the landscape, trees, and totally eclipsed Sun. The images were later processed and stacked to produce the final composite.

FRED ESPENAK (2)

■ Astronomer FRED ESPENAK manages the websites **eclipse-wise.com** and **MrEclipse.com**. Meteorologist JAY ANDERSON has researched eclipse weather forecasts since 1979 and dispenses meteorological information at **eclipsophile.com**.

The Little Stars That Can

Surprising new observations show novae forging a critical lightweight metal whose price keeps going up and up.

Every week or two, somewhere in our vast galaxy, an Earth-size star erupts in a nuclear blast. The tiny star's outer layers explode, unleashing a flash of light we might see as a "new star," or nova, that shines with the visual luminosity of some 100,000 Suns.

Yet the much rarer *super*novae get all the press. "Nobody cares about novae, and this is a mistake," says Francesca Matteucci (University of Trieste, Italy), who studies how stars enrich the cosmos with chemical elements. "I'm convinced that novae are very important" for the creation of new elements, she says.

Predictions of nova nucleosynthesis go back nearly half a century. In the 1970s, scientists calculated that novae could mint notable amounts of lithium, a scarce element that's now critical for modern technology. The theory later ran into trouble, but new observations have dramatically revived it.

Still, astronomers don't know how often novae occur and therefore can't quantify how much these explosions contribute to the Milky Way's supply of chemical elements. Plus, novae no longer light up the skies the way they once did. First-magnitude novae used to appear every decade, but it's been 81 years since the last one, and at least one astronomer thinks it's *your* fault.

An Explosive Situation

At one time, astronomers thought any star could go nova — even our own Sun. In his 1940 book *The Birth and Death of the Sun*, George Gamow wrote (emphasis in original): "We

▲ **GK PERSEI** In 1901, the white dwarf in this binary system in Perseus (central "star" in blast) let off a brilliant outburst when its surface ignited in a thermonuclear explosion. Made more than a century later, this image of the expanding nova debris combines wavelengths in X-ray (blue, hot gas), optical (yellow, clumps of ejected material), and radio (pink, electrons accelerated by the shock wave).

X-RAY: NASA / CXC / RIKEN / D.TAKEI ET AL; OPTICAL: NASA / STSCI; RADIO: NRAO / VLA

must admit, to start with, that *the a priori chances of our Sun's becoming an ordinary nova once during its total life period are fairly high*."

Fortunately, we no longer have to fear this disaster. You can thank Merle Walker, who in 1954 used Mount Wilson's 100-inch reflector to observe a star in Hercules that had gone nova 20 years earlier. He found it wasn't a single star like the Sun but instead an *eclipsing binary*. The pair's orbital period of just 4 hours and 39 minutes was the shortest such period then known and meant the two stars must be close together in order to revolve this quickly.

So . . . maybe *all* novae come from close binaries? Bingo! In the 1960s Robert Kraft studied 10 old novae, including the one in Hercules, and came to this very conclusion.

Today, we know that a classical nova occurs when gas from a companion star falls onto a white dwarf, a superdense star that was once the core of a red giant (*S&T:* Dec. 2022, p. 28). A white dwarf's surface gravity is roughly 100,000 times greater than Earth's. So as more and more gas piles up, the extreme gravity compresses the gas, which makes it hotter and hotter.

Eventually the bottom layer of the accreted gas gets so hot it triggers nuclear reactions, which fry the gas further. The heat stimulates more nuclear activity, raising the temperature still more, causing yet more reactions, and a nuclear runaway results.

"Temperatures get very high very fast," says Sumner Starrfield (Arizona State University), one of the scientists who in the 1970s calculated which elements novae should make. The temperature exceeds 100 million kelvin — far hotter than the Sun's center. The ensuing explosion is so bright the star reaches an absolute magnitude between –5 and –10, corresponding to a visible luminosity between 10,000 and 1 million times that of the Sun. Both the white dwarf and its partner survive, only to repeat the fireworks 10,000 to 100,000 years later.

From this theory, several deductions follow. First, our solitary Sun won't explode — even after becoming a white dwarf. Nor will the nearest white dwarfs, such as Sirius B, Procyon B, and 40 Eridani B, because they're far from their partners. Still, if Sirius B did explode tonight, it would outshine Venus and might even rival the Moon, peaking between apparent magnitudes –8 and –13.

Naming Novae

A nova is named for the genitive of its constellation plus the year its light reached Earth. A great nova in Perseus in 1901 is therefore named Nova Persei 1901. Novae receive variable star names as well; that one is also called GK Persei. If more than one nova had erupted there that year, the first to be recognized would have been Nova Persei 1901 No. 1, then Nova Persei 1901 No. 2, and so on.

Only two constellations have sported as many as five novae in our galaxy during a single year. If you know the sky and the structure of the Milky Way, you can probably guess which constellations they are. The first is the home of the galactic center and hosts hordes of distant stars, Sagittarius. The second is one of its zodiacal neighbors, Scorpius. In 2012 five and possibly six novae erupted in Sagittarius, and in 2021 five appeared in Scorpius.

But some constellations have never had even one recorded nova. Surprisingly, one is right next to Sagittarius in the zodiac: Capricornus. And the largest constellation of all, Hydra, has yet to have a recorded nova. Amusingly, Ursa Major, the large constellation best known for the Big Dipper, has never had a known nova, either, whereas its much smaller sidekick, Ursa Minor, has eked out one.

Furthermore, novae don't come from spring chickens. It takes time for a star to turn into a white dwarf and time for the pair of stars to cozy up to each other. Matteucci estimates that well over a billion years must elapse before novae start going off in a galaxy.

A Niche for Novae

But what good are novae? A *super*nova from a massive star showers a plethora of life-giving elements into space. In fact, with every breath you take, you inhale oxygen forged in 160 million different massive stars that went supernova, according to Matteucci and Donatella Romano (Italian National Institute for Astrophysics, Bologna). Just one massive star can launch a full solar mass of new oxygen into the galaxy.

Pretty hard for a mere nova to compete with that! The typical nova ejects only 0.01% to 0.001% solar mass of material into space. It's like a 10-year-old setting up a lemonade stand to challenge a giant corporation that sells the stuff by the ton.

So how could a nova make its mark on the cosmos? Why, create an element that no other star makes.

The most promising element turns out to be lithium (atomic number 3), a rare and increasingly important metal here on Earth. But lithium's story in novae actually starts with another element, beryllium (atomic number 4), which is even rarer in space than platinum. Stars don't make beryllium; that's why the element is so rare on Earth. Its one stable isotope, beryllium-9, arises between the stars, when cosmic rays smack into interstellar atoms, splitting either them or themselves.

But a nova explosion drives helium-3 into helium-4, forging unstable beryllium-7. Normally the nova's high temperature would destroy the element, but here, there's a way to rescue it instead: "Get it out of there — get it to low temperatures as fast as possible," says Starrfield. The nova's blast spirits the beryllium-7 away to safety. The isotope is radioactive, with a half-life of 53 days, and decays into lithium-7, the isotope that accounts for 92.4% of Earth's supply.

Lithium is rare, but it's 90 times more common in the cosmos than beryllium. Perhaps 10% of terrestrial lithium came from the aftermath of the Big Bang (*S&T:*

DANGEROUS DANCE In a nova system, a white dwarf siphons material from a companion star (here, a red giant). The material piles up on the white dwarf's surface until it's so hot and dense that it erupts in a nuclear blast.

ESO / M. KORNMESSER

May 2022, p. 20) and another 20% from the same interstellar crossfire that created Earth's beryllium. Much of the rest, however, probably came from novae. So if lithium-ion batteries power your cell phone or your electric car, you can thank the hard work of numerous novae.

For a long time, though, no one saw any lithium in novae, and some scientists even doubted that novae made the element. Nevertheless, Matteucci says nonexploding stars hold a vital clue: Most old stars have equally low levels of lithium, while young stars have much more. Thus, something has made lithium during the lifetime of the galaxy, steadily enriching the interstellar gas that forms stars. Moreover, the uniformly low lithium level among old stars means the source is something that took a while to get its act together — in other words, something like novae.

Then, in 2013, two different astronomical teams saw the creation for themselves.

Element of Surprise

Akito Tajitsu (National Astronomical Observatory of Japan) and his colleagues pointed the Subaru Telescope at a nova in Delphinus, detecting spectral lines at difficult-to-observe near-ultraviolet wavelengths. "The beryllium-7 absorption was very strong," he says. "The amount we observed was about 10 times larger than the theoretical expectation. That was really a surprise for us."

The beryllium must have decayed into lithium. "This is the first clear evidence that lithium is produced in a nova explosion," says team member Wako Aoki (National Astronomical Observatory of Japan). "I was quite surprised and very excited."

So unexpected was the beryllium-7 discovery that the Japanese astronomers didn't publish it until two years later. Meanwhile, a team led by researchers in Italy observed another nova. Peaking at third magnitude, Nova Centauri 2013 was the brightest nova of the 21st century so far.

"It was very surprising," says Luca Izzo (now Niels Bohr Institute, Denmark), who detected not beryllium but neutral lithium in the blast. A nova should strip each lithium atom of the electron that makes the red spectral line the astronomers observed. Nevertheless, they saw much more lithium in the nova than theory predicted, just as the Japanese had seen much more beryllium. Izzo's team also waited two years to publish the finding.

Since these discoveries, both teams have detected beryllium-7 in many more novae. Izzo's team even saw beryllium-7 in two novae that appeared in another galaxy, the Small Magellanic Cloud, in 2019 and 2020 as well as in RS Ophiuchi, a recurrent nova in the Milky Way that exploded in 2021.

So just how much of Earth's lithium-7 came from novae? Tajitsu estimates about 50%. Izzo says about 70%. Matteucci thinks about 75%. Aoki estimates 70% to 80%. Starrfield says about 90%. If these scientists are right, about half or more of the lithium in your cell phone was forged in nova explosions in the galaxy.

Oh, the irony! This is the most fragile of all naturally occurring chemical elements. The protons and neutrons in the nucleus of its dominant isotope are more weakly bound to one another than is the case for any other element. Yet lithium owes much and perhaps most of its existence to the violence of a nuclear explosion. It's as if an atomic bomb somehow spawned the most delicate of flowers.

Rare Isotopes

Theoretical calculations indicate that novae also produce rare isotopes of three of the most common elements in the universe: carbon, nitrogen, and oxygen. To see how, we need to look further at what happens in a nova.

When the accumulated gas on a white dwarf goes nuclear, hydrogen fuses with itself to make helium. But this reaction slowly raises the temperature so that the CNO cycle eventually takes over, in which carbon, nitrogen, and oxygen catalyze the hydrogen-to-helium reaction. Along the way this sequence produces carbon-13, nitrogen-15, and oxygen-17. Like beryllium-7, they survive the explosion, because it blasts them into the deep freeze of space.

Scientists have long used some of these rare isotopes to track the past. For example, living creatures prefer carbon-12 over carbon-13, so ancient rocks enriched in the lighter isotope suggest that life once inhabited them even if it left behind no fossils. Nitrogen-14 escapes from a planet more easily than heavier nitrogen-15, so the ratio of those two isotopes probes the atmospheric evolution of Earth and Mars.

The Nova Rate

Exactly how much nova nucleosynthesis contributes to the galaxy depends on how many novae occur each year — a number no one knows. "There's a lot of uncertainty in estimating the nova rate for our galaxy," says Allen Shafter (San Diego State University), who has spent most of his career trying to do just that.

Nowadays, observers usually find between 5 and 15 novae in our galaxy each year. Most novae are distant and therefore appear near the galactic plane. Since the Milky Way is so large and dusty, many novae go unseen, which means the true rate is greater.

Classical versus Recurrent Novae

Unlike supernovae, which normally mark the deaths of stars, novae repeat. A *classical nova* is one in which the interval between explosions is so long that astronomers have seen only one eruption. In contrast, so-called *recurrent novae* explode much more often. Examples include RS Ophiuchi, T Pyxidis, and U Scorpii.

One way to estimate that rate is to use known novae and then extrapolate to include those too far to see. In 2022 Adam Kawash (Michigan State University) and his colleagues used the Gaia spacecraft and the All-Sky Automated Survey for Supernovae to deduce an annual nova rate of about 26.

A second way to estimate the nova rate is to observe another galaxy, where we can presumably see all novae, and extrapolate its rate to the Milky Way. In 2022 Travis Rector (University of Alaska, Anchorage), Shafter, and their colleagues used more than two decades' worth of observations to find that about 40 novae appear each year in the Andromeda Galaxy. Andromeda resembles the Milky Way but probably emits more light. If the Milky Way's luminosity is 70% that of Andromeda — which is only an estimate, since we can't see the Milky Way from the outside — then our galaxy's nova rate should be around 28 a year.

In 2021 Kishalay De (now MIT) and his colleagues used infrared observations of the Milky Way that penetrate interstellar dust. From the number of novae these scientists detected, they estimated a somewhat higher nova rate, around 44 a year.

Shafter currently favors an annual nova rate around 30. That's close to the number of 25 that Starrfield's team had

DENNIS DI CICCO & SEAN WALKER / MDW SKY SURVEY (2)

▲ **NOVA CASSIOPEIAE 2021** *Left:* Discovered on March 18, 2021, this nova (orange star at center) rose to fifth magnitude before it faded. It's around magnitude 8 here, on March 21st of that year. *Right:* In an image taken in October 2022, the system looks unremarkable.

▲ **IN A CROWD** Novae have even erupted in star clusters — specifically in globular clusters, which are some of the most ancient denizens of our galaxy. (Most open clusters are too young for novae.) In 1860 observers saw a nova in M80 *(above)*, a globular cluster in Scorpius. A second nova, in 1938, appeared in M14 in Ophiuchus, but astronomers spotted that blast only decades later by examining old photographic plates.

assumed in the 1970s when predicting that novae contribute significant amounts of lithium to the galaxy. In contrast, supernovae occur in the Milky Way perhaps twice a *century*. So nova explosions happen 1,000 to 2,000 times more often than supernovae.

Where Have All the Bright Novae Gone?

However, a specter haunts these calculations: Bright novae seem to have vanished.

During the first half of the 20th century, a nova peaked at first magnitude or brighter each decade. The first, Nova Persei 1901, hit magnitude +0.2 and rivaled Rigel in brightness. Next came the brightest nova ever known, Nova Aquilae 1918, which attained magnitude -1.1 and almost surpassed Sirius. The following decades featured Nova Pictoris 1925, reaching magnitude +1.0; Nova Herculis 1934, peaking at magnitude +1.3; and finally Nova Puppis 1942, climbing to magnitude +0.5.

And the 80-plus years since? Nothing at all: The brightest blast was second-magnitude Nova Cygni 1975. "That's a scandal," says Bradley Schaefer (Louisiana State University). He thinks those bright novae are still appearing in our sky. "No one spots them! It's horrifying."

Schaefer blames a shift in observing habits. Starting around 1890, talented amateur astronomers made a sport of finding novae. These observers memorized the naked-eye stars and searched the sky for new ones. After World War II, war-surplus binoculars flooded the country, giving amateurs the chance to find fainter and farther novae. But because distant novae congregate in the band of the Milky Way, that's where amateurs conducted their searches. As a result, he says, the brightest and nearest novae, outside that band, were missed. Increasing light pollution has only exacerbated the problem by masking novae as they brighten and fade.

But Shafter is skeptical of this claim, saying the disparity is "probably just due to small-number statistics." In 2017 he calculated that the difference between the earlier era and the modern one has a 10% chance of being a statistical fluke. That's about the same chance you can flip a fair coin and get heads three times in a row. Most scientists consider such a significance level suggestive but not definitive.

Schaefer calculates the odds differently: "It's significant past the 3-sigma level," which means a 0.3% significance level — equivalent to getting eight or nine heads in a row. "That's not a fluke." He says modern observers fail to find about half of the brightest novae.

But Starrfield can't believe amateur astronomers would miss novae as bright as first or second magnitude. "These guys really know the sky," he says. "I don't know the sky at all; I mean, I'm lucky to find Jupiter."

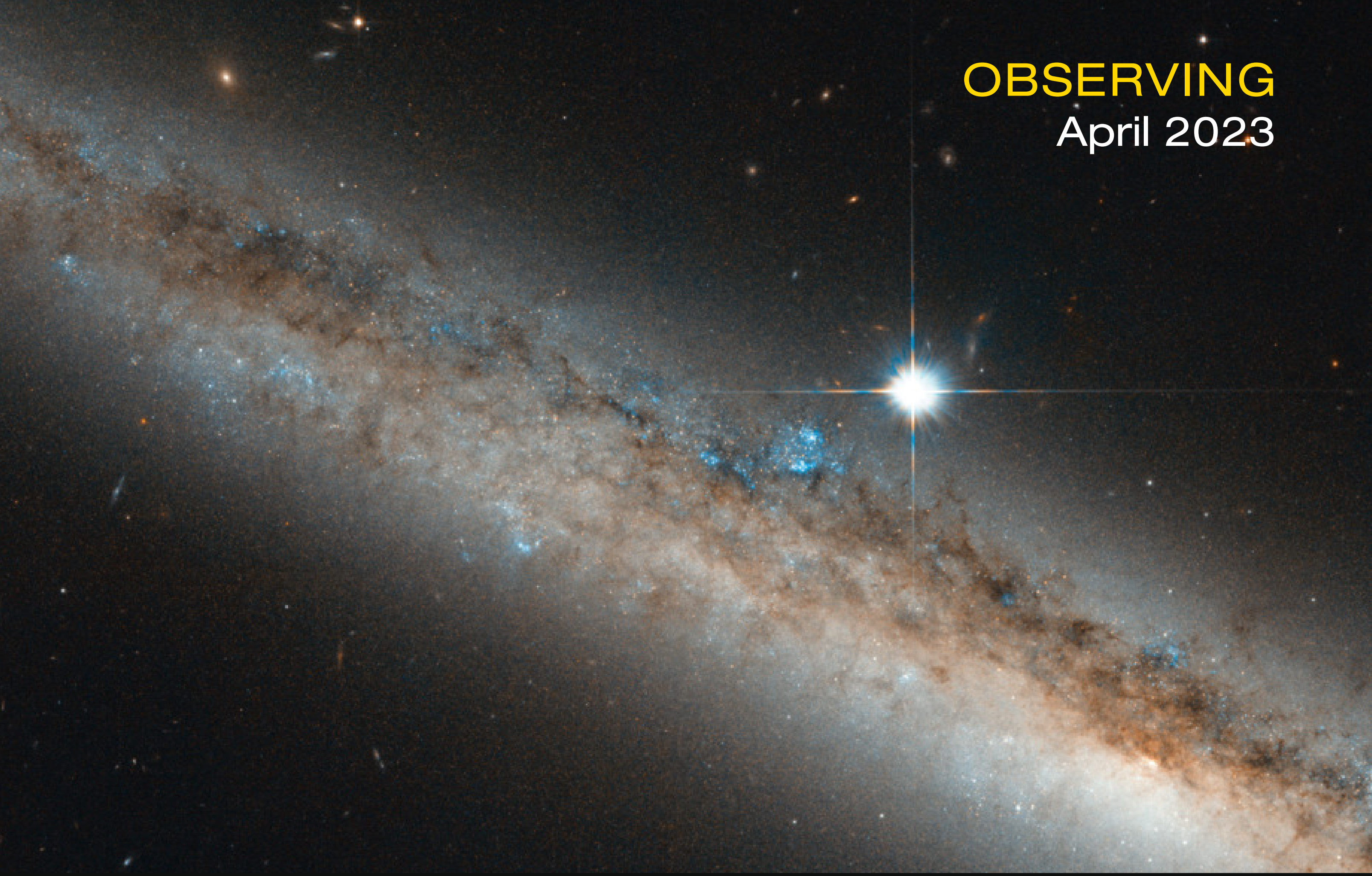
Whatever the case, someday — or, more precisely, some night — the next bright nova will shine. Why not be the one who finds it? Scanning the whole sky with the naked eye before peering through a scope might yield that long-overdue bright nova — and you'll make astronomical history.

■ **KEN CROSWELL** has neither a cell phone nor a car, but he does like nucleosynthesis.

All Known Novae of First Magnitude and Brighter from 1900 to 2022

Name	Variable-Star Name	Brightest Apparent Mag(v)	Distance (ly)	Orbital Period (d)
Nova Persei 1901	GK Persei	+0.2	1,420	2.0
Nova Aquilae 1918	V603 Aquilae	–1.1	1,060	0.14
Nova Pictoris 1925	RR Pictoris	+1.0	1,630	0.15
Nova Herculis 1934	DQ Herculis	+1.3	1,620	0.19
Nova Puppis 1942	CP Puppis	+0.5	2,550	0.06

HUBBLE HERITAGE TEAM (AURA / STSCI / NASA)



OBSERVING
April 2023

2 **MORNING:** If you're up in the wee hours, face west to see the waxing gibbous Moon sink toward the horizon in tandem with Regulus, Leo's brightest star. Less than 4° separates the pair.

6 **EVENING:** The nearly full Moon rises above the east-southeastern horizon trailing Spica, Virgo's lucida, by less than 5°.

9–10 **ALL NIGHT:** Look low in the southeast to see the waning gibbous Moon climbing above the horizon a smidgen more than ½° from Antares, the Scorpion's heart. See page 46 for more on this and other events listed here.

10,11 **EVENING:** Venus is positioned some 2½° left of the Pleiades. This view will greet you above the west-northwestern horizon.

14 **EVENING:** Look high in the west to see Mars less than ¼° left of Epsilon (ε) Geminorum.

16 **DAWN:** Turn toward the east-southeast to spot the waning crescent Moon less than 5° below Saturn. Catch this sight before the rising Sun burns it away.

20 **NEW MOON (4:13 AM EDT)** A hybrid solar eclipse will be visible from small slivers of western Australia, easternmost Indonesia, and Timor-Leste. Wider swaths will see a partial eclipse (turn to page 48 for details).

22 **DUSK:** The waxing crescent Moon hangs pleasingly in Taurus between Venus (less than 6° upper left) and the Pleiades (around 7° lower right). Look toward the west-northwest to take in this view.

22–23 **ALL NIGHT:** The Lyrid meteor shower peaks. The waxing crescent Moon sets before midnight and won't interfere with viewing (go to page 50).

23 **DUSK:** Still in Taurus, the Moon is now a bit more than 5° upper left of Venus.

25 **EVENING:** Climbing ever higher, the Moon, two days shy of first quarter, gleams less than 3° right of Mars. The pair are in Gemini, high in the west.

27 **EVENING:** High in the southwest the first-quarter Moon gleams about 4° above the Beehive Cluster (M44), in Cancer.

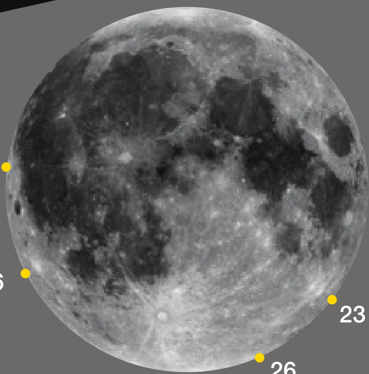
29 **EVENING:** The Moon returns to Leo where now, again waxing gibbous, it sits 5° upper left of Regulus. Look high in the south to witness this sight.
— DIANA HANNIKAINEN

▲ NGC 4517 is a nearly edge-on spiral galaxy in the constellation Virgo. The bright star is in our own galaxy, the Milky Way, but the superposition of the two objects makes for a pretty picture. Read more on Virgo galaxies on page 20. ESA / HUBBLE / NASA

APRIL 2023 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

FULL MOON
April 6
04:35 UT

LAST QUARTER
April 13
09:11 UT

NEW MOON
April 20
04:13 UT

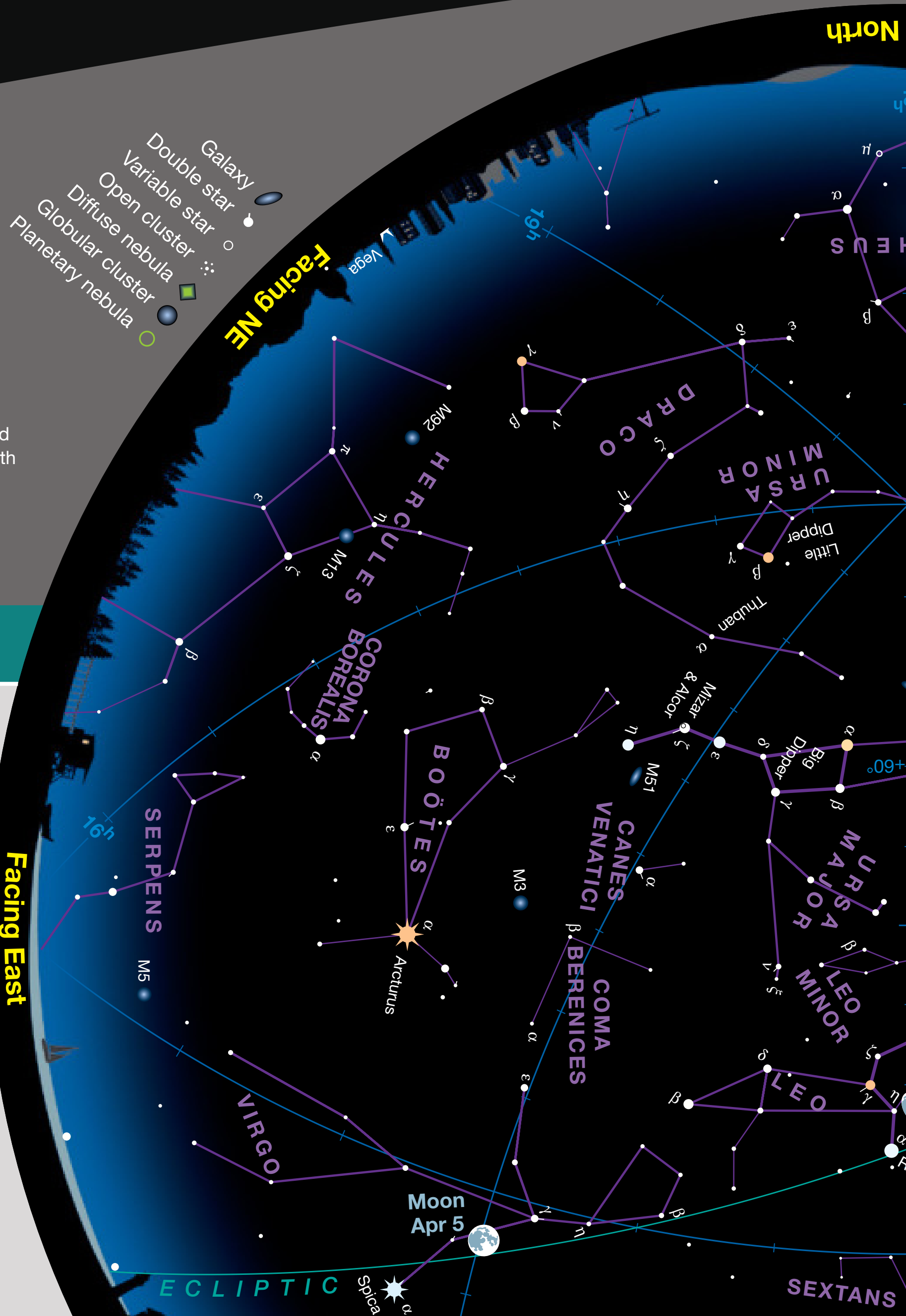
FIRST QUARTER
April 27
21:20 UT

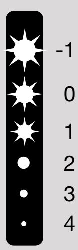
DISTANCES

Perigee	April 16, 02^h UT
367,970 km	Diameter 32′ 28″
Apogee	April 28, 07^h UT
404,299 km	Diameter 29′ 34″

FAVORABLE LIBRATIONS

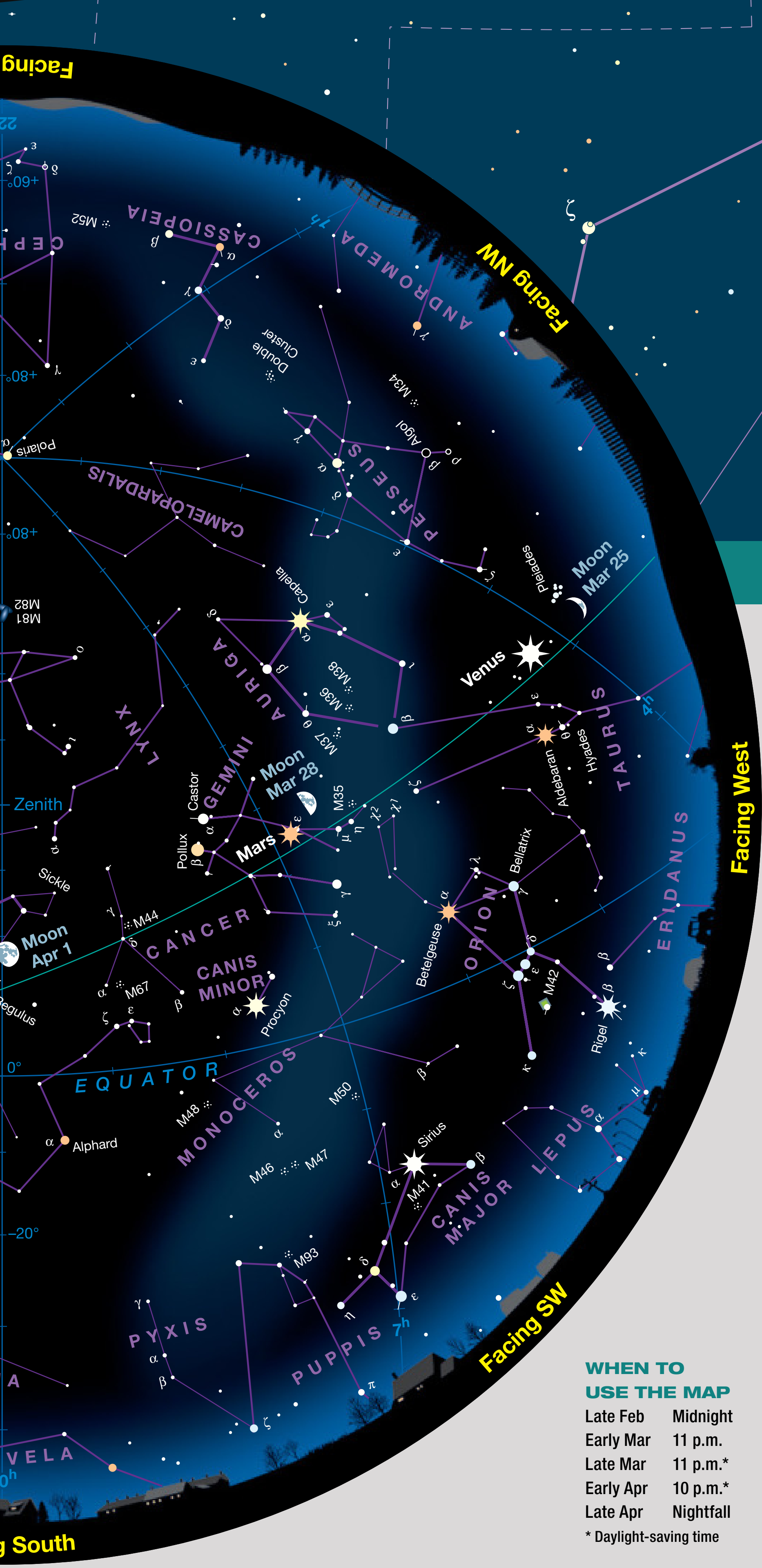
• Pettit Crater	April 6
• Glushko Crater	April 8
• Abel Crater	April 23
• Helmholtz Crater	April 26

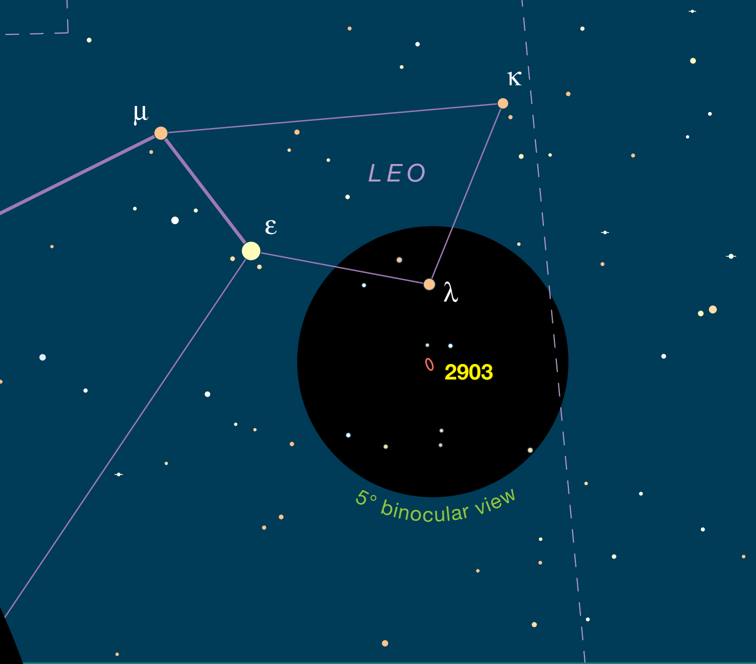




Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

The Mouse and the Lion

I'm a sucker for an underdog. I love small, dim constellations, obscure objects, the shoulda-been-Messiers, and the less popular neighbors of whatever's on the "Best of" lists. I also like pushing my binoculars, and myself, to see as much as possible.

Given all these proclivities, it might seem a little odd that it's taken me this long to cover **NGC 2903**, a barred spiral galaxy in Leo, the Lion. I don't see a lot of chatter about this rather isolated gem, but at magnitude 9.0 it's brighter than any of the Messier galaxies in Leo other than M66, which just barely edges it out at 8.9. NGC 2903 is an easy find, too: Drop down 1.5° straight south from 4.3-magnitude Lambda (λ) Leonis and look for a tiny wisp of light. There's nothing else nearby, giving the galaxy the lonely aspect of a mouse before the mighty celestial lion.

Now, in all honesty, NGC 2903 is not going to punch you in the retinas. It's a challenge object in 7×50 binos, requiring dark skies and good dark adaptation. The galaxy is an easier catch in 10×50s, but I wouldn't call it obvious unless you jump up to 15×70s. Instead, the thrill of hunting galaxies with handheld optics is not the visual splendor of the views, but the pleasurable tingle of reaching far beyond our own Milky Way — 30 million light-years beyond, in the case of NGC 2903. You can get a real sense of the scale of the universe when the combined light of billions of stars is compressed into a pale glow by unfathomable cosmic distances.

One more nice thing about celestial underdogs: Roughly a zillion of them wait to be discovered. Let's get hunting!

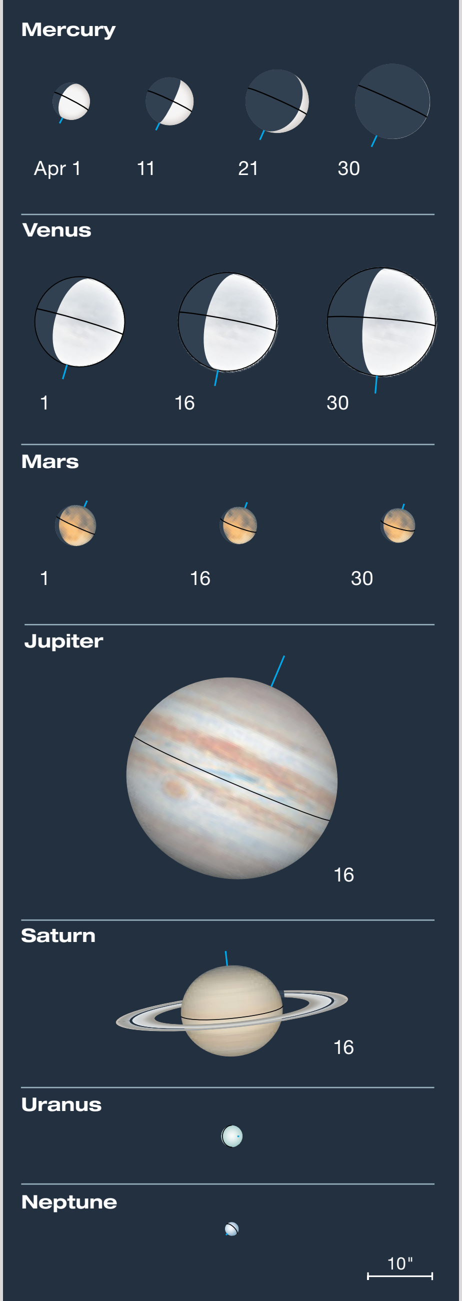
■ How would **MATT WEDEL** describe the tiniest, faintest binocular galaxy? Still pretty mind-blowing!

WHEN TO USE THE MAP

Late Feb	Midnight
Early Mar	11 p.m.
Late Mar	11 p.m.*
Early Apr	10 p.m.*
Late Apr	Nightfall

* Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk to the 21st • **Venus** visible at dusk all month • **Mars** high in the southwest at dusk and sets in the predawn • **Jupiter** lost in the Sun's glare all month • **Saturn** visible at dawn all month.



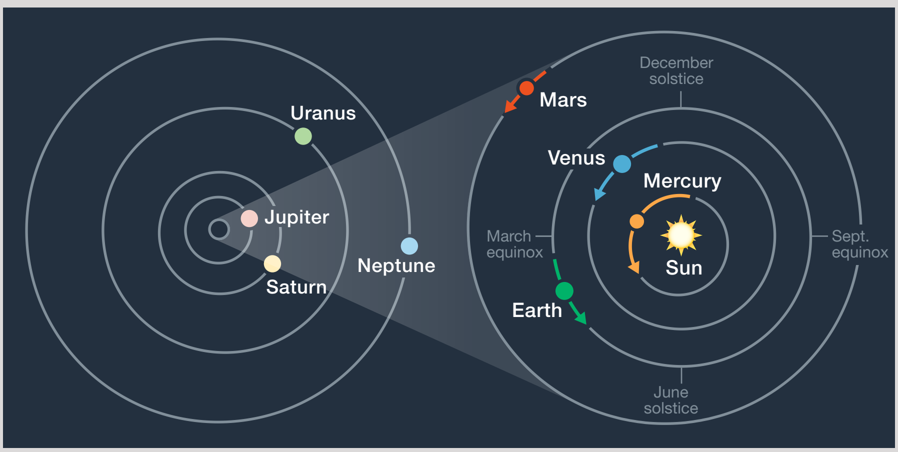
April Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$0^h\ 39.3^m$	+4° 14′	—	–26.8	32′ 01″	—	0.999
	30	$2^h\ 26.8^m$	+14° 31′	—	–26.8	31′ 46″	—	1.007
Mercury	1	$1^h\ 31.2^m$	+10° 33′	14° Ev	–1.1	5.8″	80%	1.151
	11	$2^h\ 26.1^m$	+17° 14′	19° Ev	–0.2	7.5″	43%	0.898
	21	$2^h\ 47.8^m$	+19° 09′	15° Ev	+2.0	9.9″	13%	0.678
	30	$2^h\ 37.7^m$	+16° 42′	3° Ev	—	11.7″	0%	0.573
Venus	1	$2^h\ 59.8^m$	+18° 02′	37° Ev	–4.0	14.0″	77%	1.192
	11	$3^h\ 47.6^m$	+21° 30′	39° Ev	–4.1	14.8″	74%	1.125
	21	$4^h\ 36.6^m$	+24° 05′	41° Ev	–4.1	15.8″	70%	1.055
	30	$5^h\ 21.1^m$	+25° 31′	42° Ev	–4.2	16.9″	67%	0.989
Mars	1	$6^h\ 12.7^m$	+25° 28′	82° Ev	+1.0	6.4″	90%	1.454
	16	$6^h\ 46.7^m$	+24° 55′	75° Ev	+1.2	5.9″	91%	1.599
	30	$7^h\ 19.6^m$	+23° 58′	69° Ev	+1.3	5.4″	91%	1.729
Jupiter	1	$1^h\ 11.0^m$	+6° 23′	8° Ev	–2.0	33.2″	100%	5.939
	30	$1^h\ 37.2^m$	+8° 58′	13° Mo	–2.0	33.3″	100%	5.928
Saturn	1	$22^h\ 19.5^m$	–11° 51′	38° Mo	+1.0	15.7″	100%	10.577
	30	$22^h\ 29.5^m$	–10° 59′	64° Mo	+1.0	16.3″	100%	10.203
Uranus	16	$2^h\ 59.6^m$	+16° 41′	22° Ev	+5.8	3.4″	100%	20.582
Neptune	16	$23^h\ 46.9^m$	–2° 42′	30° Mo	+8.0	2.2″	100%	30.779

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.

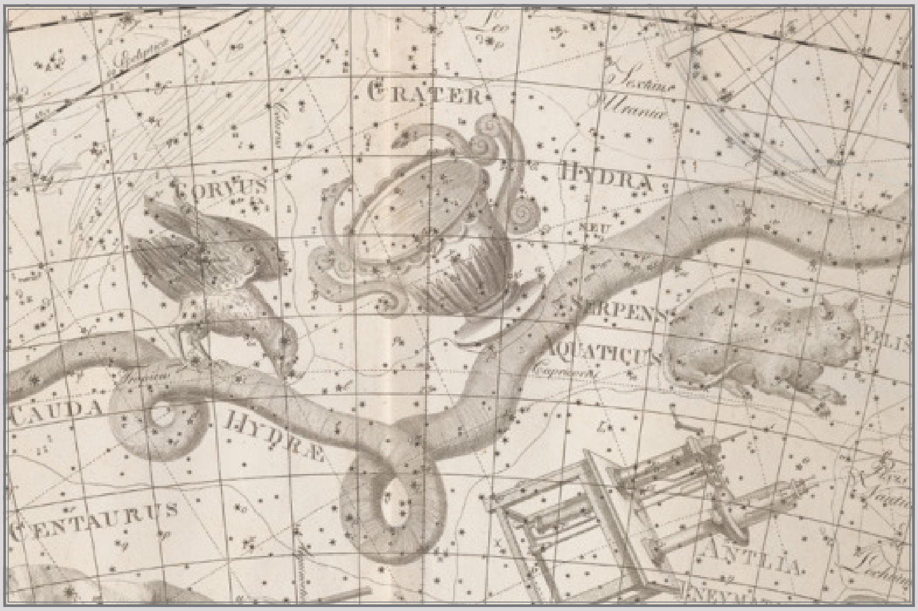
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during April. The outer planets don't change position enough in a month to notice at this scale.



Corvus and Company

This little constellation can guide you to spring sky delights.



▲ **CELESTIAL CROW** Corvus, the Crow, keeps close company with Crater (the Cup) and Hydra (the Water Snake) but has connections to many other constellations north and south.

This month let's look at the many marvelous and helpful connections that Corvus, the Crow, has with other constellations. In last May's column, I focused on the stars outlining the rhombus or sail shape of Corvus. That pattern reaches its highest point in the sky around midnight in April and on May evenings. So, there's plenty of time for the Crow to guide us to springtime sights.

Let's begin with Corvus's relation to one of the sky's brightest stars, 1st-magnitude Spica, in Virgo. The star is only about 10° from Corvus, so it provides a handy point of reference. Those learning their way around the sky for the first time might be unsure exactly which stars make up the celestial crow — especially considering that a portion of the nearby (but much dimmer) grouping, Crater, has roughly the same shape. However, Spica's proximity to Corvus quickly clears up any possible confusion about which is which.

Far less obvious than its connection with Spica are those between Corvus and several other constellations. For instance, the main pattern of Corvus is centered on –20° declination and neatly contained between the 12^h and 13^h lines of right ascension. Interestingly, Crux, the famed Southern Cross, is exactly 40° due south, lying between those same right ascension lines. Of course, Crux is so far south that it barely peeks above the horizon in the U.S. even from locations such as southern Florida and Texas. From these places, however, Corvus climbs roughly halfway to the *zenith* (the point in the sky directly overhead) and serves as a guide to locating the haze-dimmed Southern Cross as it scrapes along the horizon. The connection between Corvus and the Southern Cross also comes in handy if you're planning a stargazing trip to the Southern Hemisphere. Many of the sky's most sought-after treasures lie in the vicinity of Crux, so if you want to take in that spectacular stretch of the southern Milky Way, just remember to choose a time of year when Corvus is well placed for viewing at some point during the night.

North from Corvus, we find several more stops of interest. The *Autumnal Equinox point* (where the Sun is positioned at the start of autumn) is about 20° above (and slightly right) of Corvus. Proceeding directly north from the Crow, we traverse the telescopic wonderland of the Virgo Galaxy Cluster (see page 20) before reaching the lovely, Coma Star Cluster. Finally, turning to face north, we see the Big Dipper centered 70° to 80° due north of Corvus.

Returning to the faint constellations closer to Corvus, we have the aforementioned Crater, the Cup. Both the Crow and Cup are imagined perched on the back half of Hydra, the Water Snake. If you turn to our April evening star chart (pages 42 and 43), you'll see Hydra slithering across the meridian, but it's so long that the end of its tail has yet to rise in the southeast. The brightest Hydra star nearest Corvus is 3rd-magnitude Gamma (γ) Hydrae. It shines at essentially the same brightness as Delta (δ) and Epsilon (ε) Corvi, which mark the constellation's northeast and southwest corners, respectively.

Corvus and Crater are not only side-by-side in the sky, but they're also connected in story. In one Greek myth, Apollo punished the crow for lying about why the bird took so long to bring the god the bowl of fresh water he had requested. Corvus claimed that a snake had blocked access to the water source, when in fact the crow had been busy enjoying fresh figs. Apollo saw through the lie and condemned the bird to a life of thirst, which explains the crow's raspy voice. When it died, Apollo put Corvus in the sky with the bowl (Crater) and the snake (Hydra).

An Aesop fable has a more pleasant connection between Corvus and Crater. In this tale, a thirsty crow placed pebbles in a cup to raise the water level until it was high enough for the clever bird to finally have a satisfying sip.

■ **FRED SCHAAF** remembers watching the tail of Halley's Comet brightening and lengthening as it spread across Corvus in April 1986.

JOHANN BAYER / IOANNIS BAYERI RHAINANI VRANOMETRIA / POLONA DIGITAL LIBRARY / PUBLIC DOMAIN

To find out what's visible in the sky from your location, go to skyandtelescope.org.

A Planetary Trio at Dusk

Mercury, Venus, and Mars enjoy a series of eye-catching conjunctions.

SUNDAY, APRIL 9

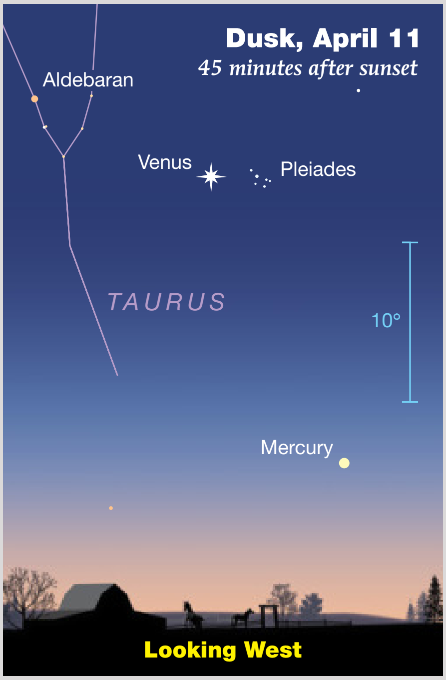
Each month the **Moon** visits several of the bright stars that adorn the *ecliptic*, the path it treads across the night sky. Tonight, the waning gibbous Moon rises just before midnight alongside **Antares**, the brightest star in Scorpius and the second-brightest of the ecliptic stars. The two are at their very closest at 2:02 a.m. EDT on the 10th. At that moment, the Moon sits just a bit more than ½° (one lunar diameter) left of the orange, 1st-magnitude star. Binoculars will help you appreciate Antares's tint, and you'll probably notice it flickering quite vigorously, too. That's because the star's light is being distorted by the thick layer of atmosphere present near the horizon. As it climbs higher (along with the Moon), the twinkling effect will gradually diminish.

The Moon usually meets Antares once a month, and while this morning's conjunction is a good one, the absolute highlight of the year's get-togethers will occur in late August when the Moon actually eclipses the star for observers in much of North America. Something to look forward to when you gaze at the twosome on this night.

MONDAY, APRIL 10

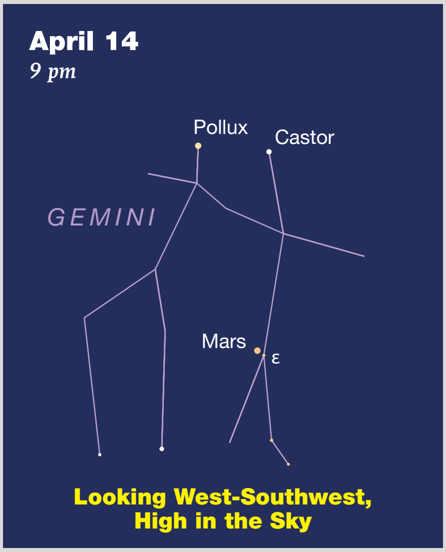
This evening and the next, **Venus** will be within hailing distance of the **Pleiades** in Taurus. On both occasions the brilliant planet sits a bit more than 2½° from the cluster's brightest star, 2.9-magnitude Eta (η) Tauri, otherwise known as Alcyone. That means Venus and the Pleiades will comfortably fit in the same binocular field, which allows you to appreciate the view even in fading twilight. A beacon of magnitude –4.1, Venus should be easy to see soon after sunset. But how much later will the cluster's stars begin to emerge? Try spotting them with binoculars first and then with your unaided eyes.

While you're appreciating the view, take a moment to cast your gaze down toward the west-southwestern horizon to catch **Mercury**. It reaches its greatest elongation from the Sun on the 11th when the planet shines at magnitude –0.2. This is a splendid time to catch the swift-moving little world as it undergoes its most favorable apparition for 2023. Even 45 minutes after sunset, Mercury still hangs nearly 10° above the horizon. But don't delay. Although Mercury remains a dusk target for another 10 days, it fades rapidly. A week from now (the 18th), it will glow inconspicuously at magnitude 1.5 — almost five times fainter than at greatest elongation.

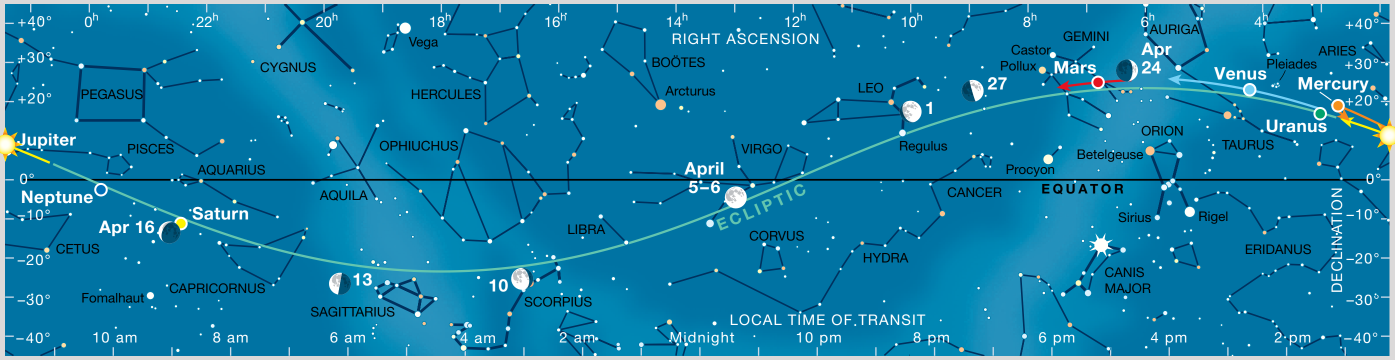


FRIDAY, APRIL 14

Shining at magnitude 1.2, **Mars** is well past its December prime. But its apparition continues with some interesting conjunctions, including this evening's near miss with 3.0-magnitude **Epsilon (ε) Geminorum**, the star otherwise known as Mebsuta. Tonight's close call occurs because Epsilon lies just 2° north of the ecliptic. If the pairing of these two objects has a familiar ring, it's because they've met before. Long-time readers of this magazine may recall



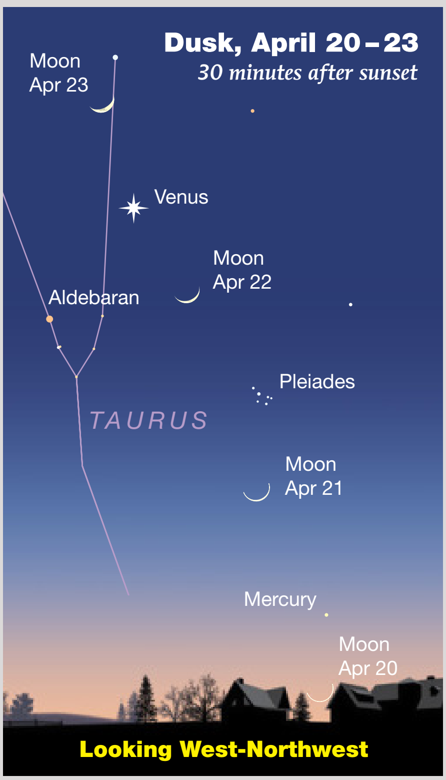
▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.



▲ The Sun and planets are positioned for mid-April; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

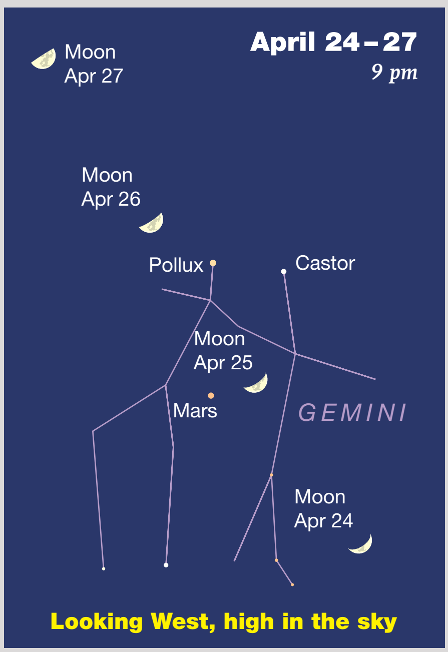
that Mars actually eclipsed Epsilon on April 7, 1976 — a much-anticipated and very rare event that attracted the interest of amateur astronomers and research groups around the world. And this evening the planet and star are as close as they've been since that fateful meeting 47 Aprils ago.

This time, Mars will approach to within 9′ of the star at 2:09 p.m. EDT. By the time twilight starts to fade in North America, the planet's eastward motion will have carried it a little farther from the star — something more like 13′. You should have no problem seeing both objects without optical aid, but binoculars will greatly enhance the view. Mars is quite close to the star on the preceding and following evenings, but this really is the best night. And you don't want to miss out — Mars won't be this close to Epsilon again until 2055.



SUNDAY, APRIL 23

Whenever **Venus** serves as the Evening Star, you're guaranteed at least one striking conjunction with the **Moon** each month. Sometimes two. Just as twilight begins to fade tonight, cast your gaze toward the west-northwest to see a pretty, earthlit lunar crescent standing some 5° upper left of brilliant Venus. That's splendid. But what makes this evening's sight extra special are the supporting players, which include Mars and the bright stars of winter marching toward the horizon. Although we've opted to highlight this date, in fact the lunar crescent is nearly as close to Venus on the preceding evening, so you really have two opportunities to catch these luminaries together. Indeed, if you are on the West Coast, the gap between the Moon and Venus is actually smaller on the evening of the 22nd.



TUESDAY, APRIL 25

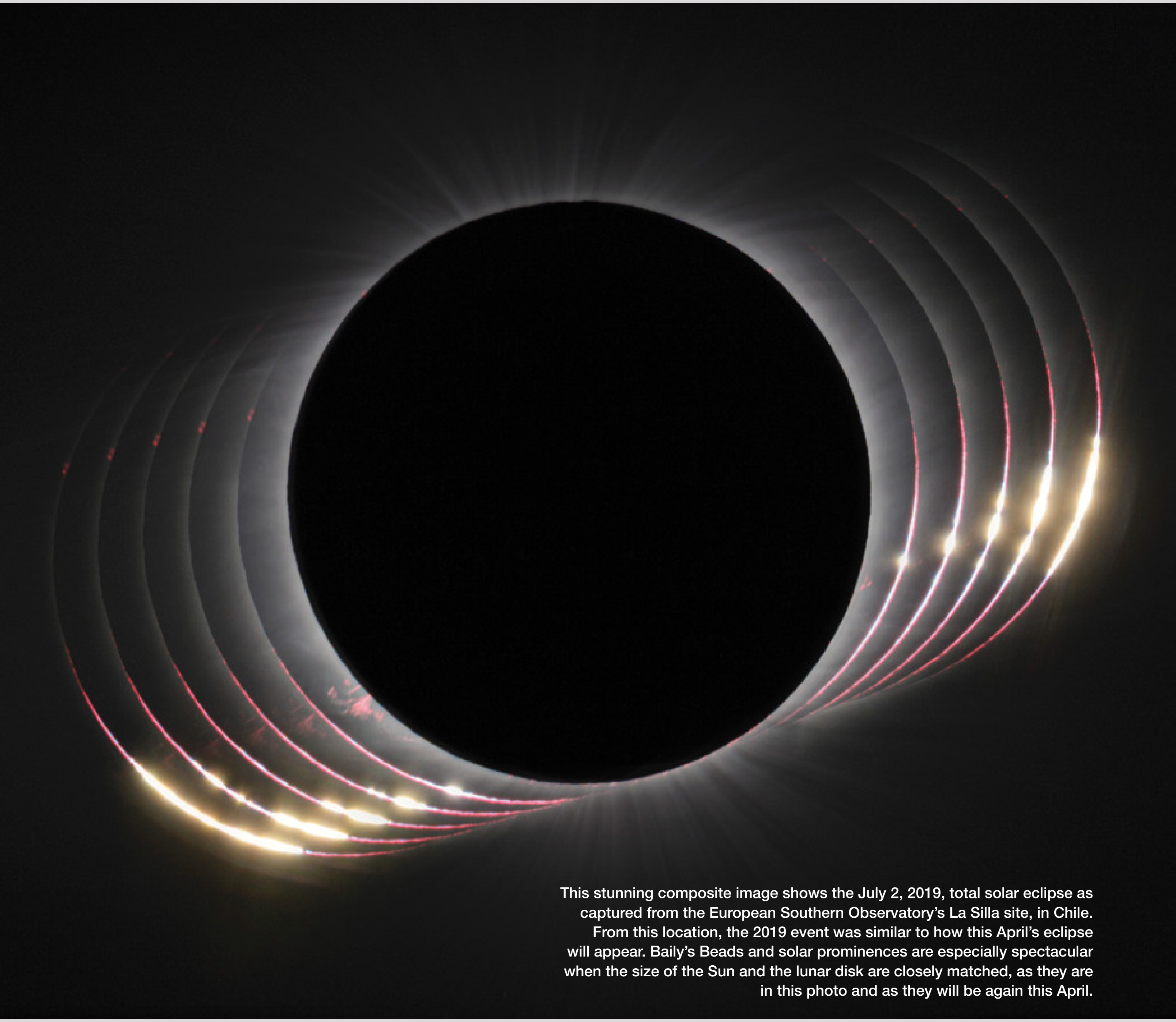
Before the month wraps up, **Mars** and the **Moon** have one last duty to perform. Tonight, they meet in Gemini, some 8° below the constellation's two brightest stars, Castor and Pollux. The waxing lunar crescent sits less than 3° right of Mars in what is the closest Moon-planet pairing this month.

In some respects, this event echoes last December's very close conjunction (or, occultation, depending on your location) but is much less spectacular. Back then, the Red Planet was at opposition and gleamed brilliantly at magnitude –1.8 while the Moon was full. Still, taken for what it is, tonight's sight is nevertheless very attractive, set as it is within the luminous Winter Hexagon and with Venus nearby for extra luster.

■ Consulting Editor **GARY SERONIK** has been keeping an eye on the sky long enough to recall the previous time Mars and Epsilon Geminorum met.

A Touch-and-Go Solar Eclipse

This unusual event will entice eclipse chasers willing to travel.



This stunning composite image shows the July 2, 2019, total solar eclipse as captured from the European Southern Observatory's La Silla site, in Chile. From this location, the 2019 event was similar to how this April's eclipse will appear. Baily's Beads and solar prominences are especially spectacular when the size of the Sun and the lunar disk are closely matched, as they are in this photo and as they will be again this April.

A rare hybrid solar eclipse will brush parts of Australia, Timor-Leste, and Indonesia on Thursday, April 20th. In this type of event, the Moon fits so snugly over the Sun that different places along the central line see either a total or an annular eclipse. Hybrid eclipses occur roughly once a decade.

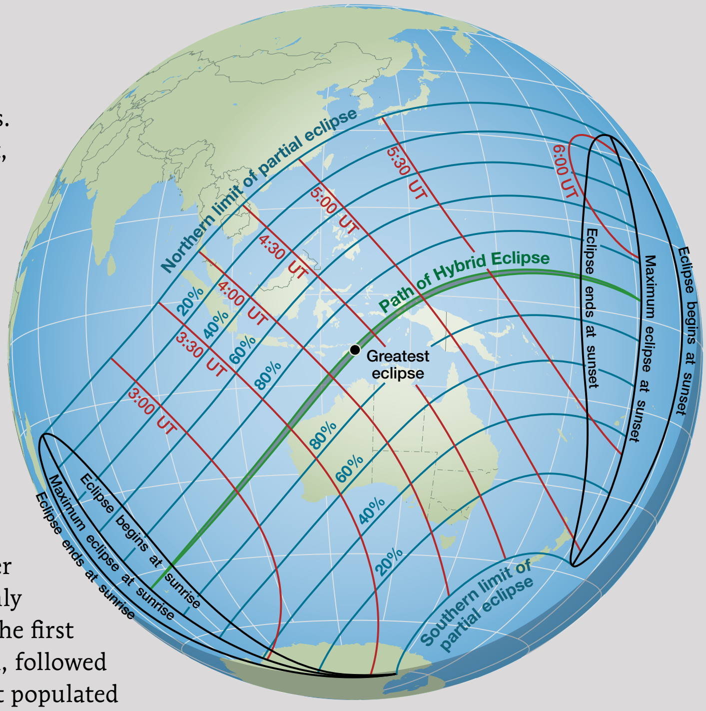
As shown in the diagram at right, the eclipse path first touches down north of the French Southern and Antarctic Lands and continues northeast across the Indian Ocean, making landfall for the first time along the western edge of Australia's North West Cape. Observers along the central line in this narrow peninsula will witness 1 minute 3 seconds of totality at 3:30 UT, with the Sun 54° above the horizon.

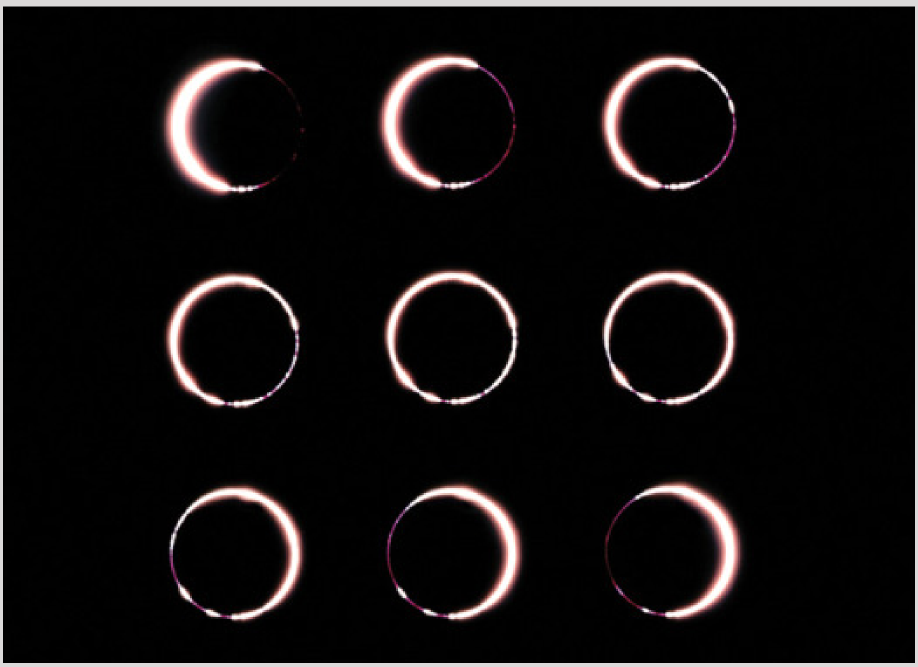
Greatest eclipse occurs at 4:17 UT in Indonesia with $1^m\ 16^s$ of totality. Three minutes later, the Moon's shadow makes landfall over the eastern half of the island of Timor in Timor-Leste, and then proceeds northeast over the Indonesian province of West Papua. As the shadow arcs south of Micronesia and the Marshall Islands, its path narrows and totality decreases to mere seconds before the eclipse transitions to a *broken annularity* phase, with sunlight shining between the mountains dotting the circumference of the lunar disk. Before the event ends at 5:57 UT, some 3,000 kilometers (1,900 miles) southeast of the Hawaiian Islands, the eclipse briefly becomes annular.

So, why does this total, broken annular, and annular sequence occur? During a total solar eclipse, the Moon casts a cone-shaped shadow with its apex below the surface of the Earth. In an annular eclipse, the apex of that cone never quite reaches the ground. Both situations occur in a hybrid eclipse, thanks to our planet's curvature. The Moon's distance from Earth's surface (our satellite's *topographic* distance) varies according to where it appears in the sky. When the Moon shines near the zenith, it hovers directly over Earth's curving surface, where the topocentric distance between the two bodies is at its minimum. Far from the zenith, Earth's surface curves away from the Moon, and the distance increases. When tolerances are tight, the curvature of our planet affects whether or not the shadow cone will kiss or miss Earth's surface.

Because the Moon's apparent size nearly matches the Sun's on eclipse day, the topocentric Earth-Moon distance varies enough to force a hybrid scenario. Solar eclipse mapper Michael Zeiler predicts only beaded annularity along the first section of the eclipse path, followed by totality across the most populated zone, then a transition back to broken annularity. Observers at the far eastern end of the central path will experience just 4 seconds of annularity before the Moon's shadow departs Earth and zooms off into space.

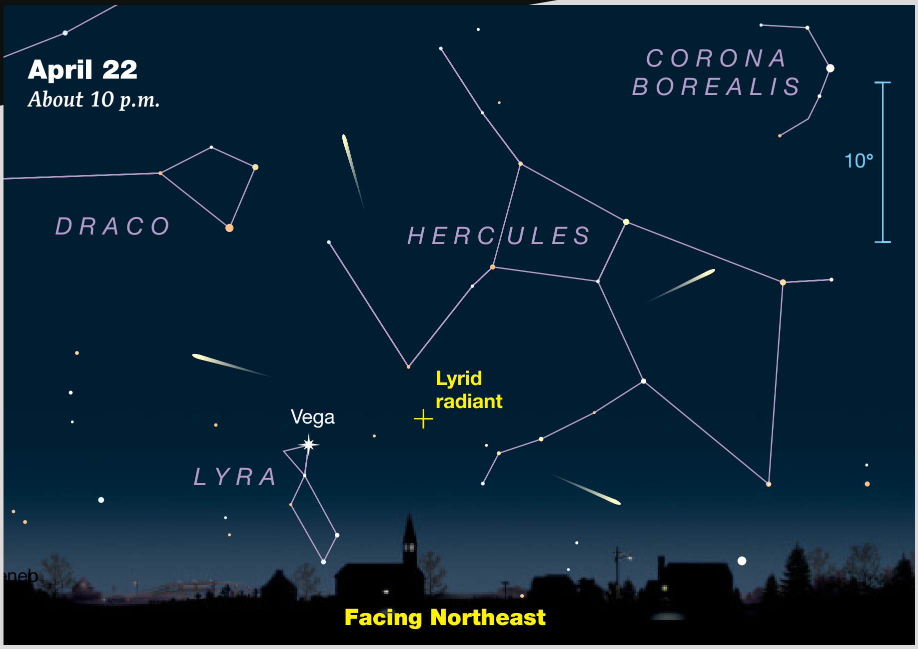
Even at maximum, totality is very brief this time, and most readers of this magazine will have to travel great distances to witness it. Thankfully, a much longer and more convenient total eclipse occurs less than a year later. Extensive details for that event can be found starting on page 26. There's also an annular eclipse due later this year for observers across the Americas, including a wide swath of the continental U.S. Our October issue will feature complete information.





▲ The progress of the beaded annular eclipse of May 30, 1984, is shown in this sequence photographed from Greenville, North Carolina. Broken annularity occurs when the vertex of the Moon's shadow falls just short of Earth's surface. Sunlight shining through low spots along the lunar limb creates a continuously changing display of Baily's Beads. Portions of April's hybrid solar eclipse will feature a similar broken-ring appearance.

TOTAL ECLIPSE SEQUENCE (FACING PAGE): PETR HORALEK; ECLIPSE GLOBE MAP: LEAH TISCIONE / *S&T*; ANNULARITY SEQUENCE: FRED ESPENAK



◀ With an early moonset, conditions for the 2023 Lyrid meteor shower couldn't be better. You can begin your meteor watch as early as 10 p.m. local daylight time on the evening of April 22nd, when twilight has fully faded and the radiant stands above the northeastern horizon. However, the best time to observe will be in the predawn hours of the 23rd when the radiant is nearly overhead for observers at mid-northern latitudes.

Looking for Lyrids

CIRCUMSTANCES COULDN'T BE better this year for the annual Lyrid meteor shower. The 9%-illuminated crescent Moon sets before midnight on the peak night of April 22–23, creating optimal conditions for this modest display. Shower members stream from a point in the constellation Hercules, some 8° southwest of the bright star Vega, in Lyra.

While Lyra will be visible in the northeast around 10 p.m. local daylight time, the Lyrid display is best viewed between 2:00 a.m. and 4:30 a.m. on April 23rd, when the radiant stands highest and before twilight begins to noticeably brighten the sky.

Under dark conditions you can expect to see about 15 meteors per hour. Outbursts with increased activity occur whenever Earth encounters denser streams of debris, as it did in 1803 and 1982. However, no similar enhancement is expected this year. Lyrid meteors generally don't have lingering trails, though the display is known for producing fireballs. The Lyrids originate from dust released by Comet C/1861 G1 (Thatcher), a long-period comet that circles the Sun every 415 years. It last reached perihelion in 1861 and will do so again in 2276.

One remarkable aspect of the Lyrids is that the display has been observed for more than 2,700 years. Although the radiant wasn't determined until the 1803 outburst, it's likely Chinese astronomers first recorded the shower as far back as 687 BC. I plan to set my alarm both for the pleasant show and to keep the chain unbroken. And if the display fizzles, at least I got to preview the summer sky.

Spot a Very Young Moon

ARE YOU CHARMED by the razor-thin lunar crescent? If you are, then face west-northwest half an hour after sunset on April 20th to catch a very young Moon. From the East Coast it will be a little less than 20 hours old and 0.7% illuminated; from the Midwest it's 21 hours old and 0.8% lit; and from the West Coast, it's 23 hours old and 1.0% lit. Since the crescent will hover just a few degrees above the horizon, find a location with an unobstructed view (looking over water is ideal) and use binoculars or a small telescope to help locate the Moon and to enhance the delicate scene.

◀ Mars reappears from behind the limb of a paper-thin lunar crescent as seen from De Soto, Kansas, shortly after the occultation of December 6, 2010. The Moon's age at the time was just 1.3 days. Low-altitude air turbulence distorts its fragile outline.

DOUG ZUBENEL

Seeing Venusian Clouds

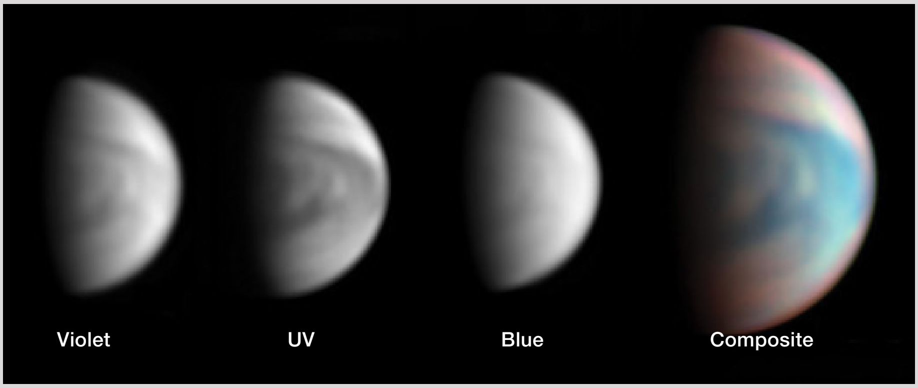
CHANCES ARE YOU'VE tracked Venus's changing phases many times in a telescope or with binoculars. Your scope may have also shown subtle brightness differences across the planet's disk from limb to terminator. But have you ever seen Venus's sulfuric-acid clouds? Few amateurs have. To discern these notoriously low-contrast features, you need good seeing, filters, and patience.

For imaging, an ultraviolet (UV) filter such as a Baader U-Venus-Filter will help. Visually, you don't need a monster telescope. An 8-inch, good seeing conditions, and a color filter or two might be all that's required. Some observers have had success with instruments with apertures as small as 4 inches. A Wratten #47 deep-blue filter is often a first choice, but some also report success with #21 orange, #23A red, and the Baader Neodymium filter, which is said to reduce glare and improve the contrast of planetary details.

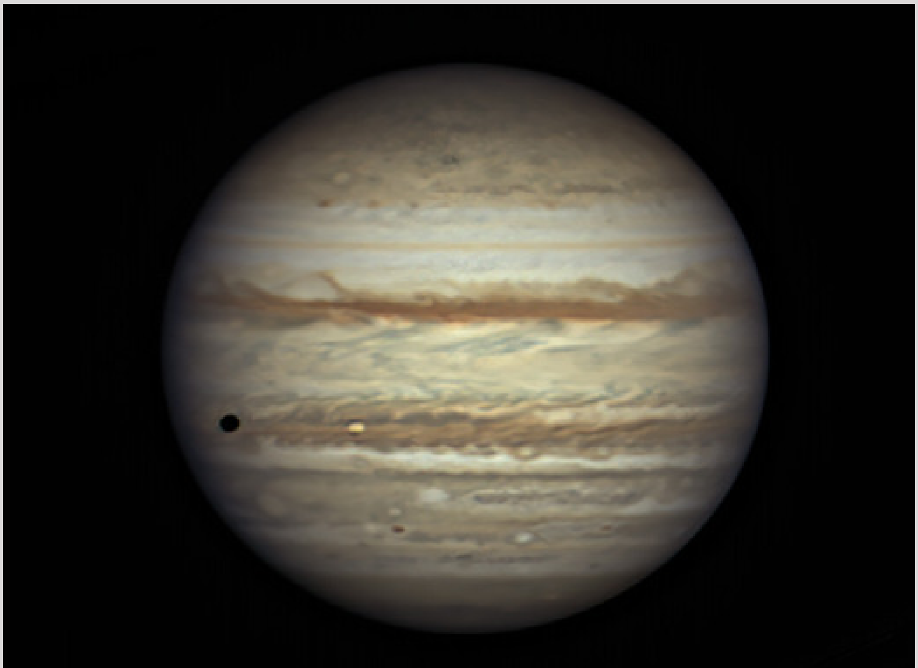
Plan your session when Venus's phase is between gibbous and a thick crescent, and the planet is at a healthy elongation from the Sun. The middle of this month is a good time to start. On the 15th, Venus is 72% illuminated, 15.3″ across, and 40° away from the Sun. By month's end its phase wanes to 67%, and its diameter increases modestly to 17″. Circumstances remain ideal through mid-June. That should give you plenty of opportunities to see cloud textures on this oft-neglected planet.

Try to observe during the daytime when Venus climbs highest in the sky. Daylight nixes the planet's overpowering glare that so often accompanies twilight viewing, while its greater altitude means steadier seeing conditions. In mid-April Venus transits the meridian around 3:30 p.m. local daylight time at a satisfying 73° altitude, as seen from a latitude of 40° north. A month later, it's even higher (76°) during its transit at around 4:00 p.m.

There are several ways to find the planet in daylight. Obviously, a properly aligned Go To scope makes short work of locating it, but a regular equatorial mount is also a good choice. Use the table on page 44 or software to get the right ascension (R.A.) and declination (Dec.) of both the Sun and Venus. Next, approximately polar-align your scope using a compass, then pop on a solar filter. After centering and focusing the Sun, offset in R.A. and Dec. using your mount's setting circles to locate Venus in a low-power eyepiece. Remove the solar filter and, if I've been diligent, the planet will appear in sharp focus in the field of view. If it's not, have a look for it in your finderscope, or sweep around a bit — you'll get there eventually.



▲ These photos taken through violet, UV, and blue filters reveal remarkable detail in Venus's clouds on September 22, 2021, when the planet was 17.6″ across and 65% illuminated. The three frames were composited and assigned colors to create the composite color image. Although Venus takes 243 days to rotate, its dense atmosphere and clouds circle the planet every four days — a phenomenon known as *super-rotation*.



Jupiter is in conjunction with the Sun on April 11th and out of view all month. As a result, our regular tables showing the transit times of the Great Red Spot and Jovian satellite events aren't presented in this issue. They will return (along with Jupiter) next month.

VENUS UV IMAGES: NIALL MCNEILL; JUPITER: SEAN WALKER / S&T

Tracking Time on the Moon

Observing these craters can help you to recognize the age of other lunar features.

Impact craters, from tiny pits to giant basins, are the dominant landforms of the Moon. Just a handful of the largest craters appear nearly unchanged since they formed over a billion years ago. The rest have been reshaped by subsequent events. In fact, modification was common in the first half-billion years of lunar history. Craters large and small were completely destroyed or otherwise altered by other impacts in the earliest lunar epoch. However, between about 3.8 and 1 billion years ago, this degradation slowed as the impact rate rapidly declined. In the last billion years, the mixing of crater rays and mare soils has become the dominant modification process (*S&T:* July 2019, p. 52).

To show the effects of crater modification over time, I've selected 10 craters ranging from 40 to 100 km (25 to 62 miles) in diameter that formed between 85 million and 3.9 billion years ago. Crater ages older than 2 billion years are from a 2013 paper by Michelle Kirchoff and colleagues at the Southwest Research Institute in Boulder, Colorado. They used the standard method of counting the number of superposed impact craters on earlier craters. The floors of these craters generally show little evidence of additional modification, so the counts should accurately reflect their ages. But at the same time the craters older than 1 billion years are statistically more likely to have experienced later modifications. Did they?

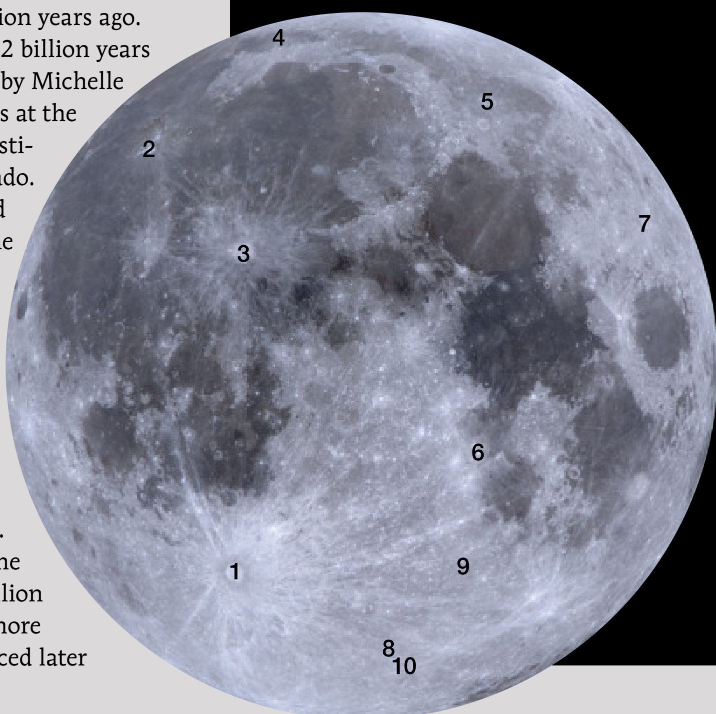
The three youngest, large, dated craters **Tycho**, **Aristarchus**, and **Copernicus** show what fresh complex craters look like — a "before" view to compare with older, more battered craters. Each of these so-called TAC craters has a high, crenulated rim and a series of terraces. Their broad, flat floors contain central peaks and many small-impact melt mounds and flows. Beyond their rims are streamers of secondary craters and rays extending hundreds of kilometers.

Harpalus is the next youngest crater on the list. With an age of 1.1 billion years, Harpalus has classic, complex crater morphology, including radial ejecta ridges and small secondary craters, but its rays are fainter than those of the TAC craters, extending only about 150 to 200 km. Close examination shows that Harpalus' inner terraces are somewhat rounded. Harpalus is the same diameter and depth as Aristarchus but has been exposed to slow and steady erosion roughly seven times longer.

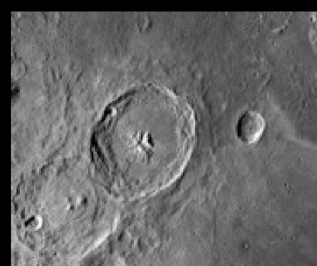
The next three have 80-to-100-km diameters, like Tycho and Copernicus, but are several times older. **Aristoteles**, **Theophilus**, and **Geminus** maintain the continuous rims, terraces, and broad floors as the TAC craters. Aristoteles has significant radial ridges and secondary craters, although its ray system is short and faint. Its terraces are less rounded than those of Harpalus, but most puz-

Crater Age Comparison

(AGE: BILLIONS OF YEARS; RAY VISIBILITY SCALE OF 0 TO 5 STRONGEST)



1. Tycho
Age: 0.1 • Diameter: 86 km
Depth: 4.7 km • Ray visibility: 5



6. Theophilus
Age: 3 • Diameter: 100 km
Depth: 4.8 km • Ray visibility: 1

zling is its lack of significant central peaks. Instead, it has small hills and two off-center peaks about 600 meters high.

The 100-km-wide crater Theophilus is Copernicus' older sibling, with a similarly tall rim, massive central peaks, multiple terraces, and a broad, flat floor. Its secondary craters pepper Mare Nectaris to the east and north, and some faint ray filaments are visible to the east. The most remarkable feature of Theophilus is the broad, flat ponds of impact melt that fill low spots just beyond its north rim crest. These are the most visible melt ponds on the nearside of the Moon. Theophilus is dated at 3 billion years old, and despite its wonderful morphology it shows its age. Its terraces and outer rim are rounded and look worn down.

The last of the 3-billion-year-old craters is the largely overlooked, 83-km-wide Geminus, north of Mare Crisium. Its rim is complete, but its extensive terraces are somewhat smoothed, and its three small central peaks are reminiscent of those in Aristoteles. None of its secondary craters or rays remain.

The final triumvirate of craters — **Pitiscus**, **Piccolomini**, and **Vlacq** — are about 3.8 to 3.9 billion years old. Pitiscus and Vlacq reside near each other in the southern highlands, where most craters are heavily modified and appear similar. They are noticeably degraded compared to the pristine TAC examples. The rims of both features are interrupted by large, younger craters, and they have additional, more recent impacts on their floors. These are all indicators of immense age. Their terraces are rounded, and their central peaks are small, apparently having been partially buried by infilling, possibly by ejecta from the Orientale and Imbrium basins (both formed about 3.8 billion years ago). Piccolomini is dated at 3.9 billion years old and retains a continuous rim, massive central peaks, and a flat floor — only its rounded terraces hint at an older age. Piccolomini looks much more like the relatively young (by 900 million years) Theophilus than the clearly battered Pitiscus and Vlacq.

This small sampling shows many telltale signs that place a crater's age. Rays fade after about a billion years, and secondary craters persist about three times longer. Terraces become noticeably less sharp and rounded after 3 billion years of weathering. With further aging, terraces evolve into featureless slopes, and central peaks become less prominent. Impacts older than 3.8 billion years are likely to have large, superimposed craters — possibly due to secondary impacts from the ejecta carved out during the formation of the large basins and craters. Even older craters, like those found north of Mare Frigoris, are ruins.

Examining this small sample of craters demonstrates that there are innate outliers, like Copernicus' shallowness and Aristoteles' deficit of central peaks, even though there are well-defined statistical relations between crater diameters, depths, and morphologies. The range of uncertainty for these and most craters dated by crater counting, rather than by analysis of lunar samples, is as high as 10% or more. Thus, the youngish-appearing Piccolomini could actually be 400 million years younger than its count-determined age, or, like some healthy 90-year-old humans, it simply may have been lucky and avoided many of the ravages of advanced age.

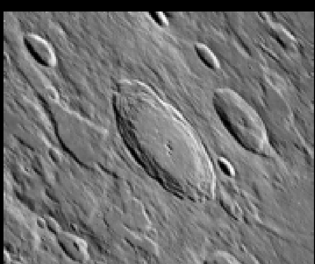
■ Contributing Editor **CHUCK WOOD** sometimes feels as old as Vlacq.

2. Aristarchus
Age: 0.2 • Diameter: 40 km
Depth: 3.2 km • Ray visibility: 5

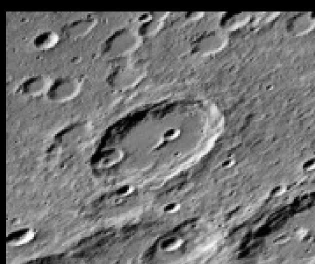
3. Copernicus
Age: 0.8 • Diameter: 97 km
Depth: 4 km • Ray visibility: 5

4. Harpalus
Age: 1.1 • Diameter: 40 km
Depth: 3.1 km • Ray visibility: 3

5. Aristoteles
Age: 2.7 • Diameter: 88 km
Depth: 3.7 km • Ray visibility: 1

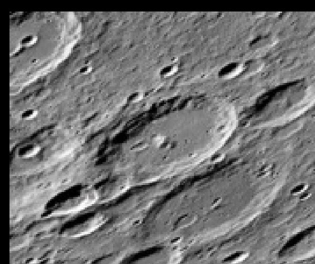


7. Geminus
Age: 3.2 • Diameter: 83 km
Depth: 3.9 km • Ray visibility: 0



8. Pitiscus
Age: 3.8 • Diameter: 82 km
Depth: 3.9 km • Ray visibility: 0

9. Piccolomini
Age: 3.9 • Diameter: 88 km
Depth: 4 km • Ray visibility: 0



10. Vlacq
Age: 3.9 • Diameter: 91 km
Depth: 4 km • Ray visibility: 0

FULL MOON: SEAN WALKER / S&T
CRATER IMAGES: NASA / GSFC / ARIZONA STATE UNIVERSITY (10)

Creating Sharp Astrophotos

Taking well-focused images of the night sky is easy if you follow these simple tips.

A poorly focused lens can ruin an otherwise perfect astrophoto. Stars become bloated blobs (often surrounded by unsightly color fringes) and fine details are lost. Imprecise focus also means longer exposures are required to record faint objects. And none of these problems can be easily fixed during post-processing — that's why it's important to get everything right under the night sky.

Your camera's autofocus system works well in bright daylight but will struggle to lock in focus in dim conditions. In fact, some excellent lenses are fully manual and lack autofocus capabilities. For best results, you need to manually focus with the aid of a feature called Live View. It's included in most every digital camera sold these days. This option allows you to zoom in and examine a highly magnified image of a bright star or planet on your camera's rear display. This technique is the only way to guarantee consistent results at night.

To Infinity . . . and Beyond

To begin, try to get close to infinity focus by rotating your lens's focus ring to its most distant setting. If it features a printed scale, you can use the infinity symbol (∞) as a handy reference; however, autofocus models go slightly past this point. If you have such a lens, turn the focus ring back a little bit from its maximum-distance setting — often there's an index mark to align with the infinity symbol. This preliminary step ensures the stars are sharp enough to show up when you engage Live View.

Now, set your camera to Manual mode with an exposure time of 30 seconds and set the lens aperture wide open (the lowest f/stop number). Increase the ISO setting to 1600 or more, and turn up the brightness of your camera's viewscreen. While this last step will ruin your night vision, it'll make seeing dim objects much easier.

▲ **SHARP LAGOON** Your time under a clear, dark sky is always limited, but it's important to take as long as you need to accurately focus your camera's lens. This crisply focused, 6-minute exposure of the Lagoon and Trifid Nebulae (M8 and M20) in Sagittarius was captured from Mount Kobau, British Columbia, with an astro-modified Canon 60D DSLR camera set to ISO 1600, and a 300-mm f/4 lens.

To use Live View, center a bright star or planet in the field of view. Gently nudge the focus ring back and forth, stopping when the blur circle is smallest. Recenter your target and increase the magnification to 5× or 10×. Tweak the focus ring again slightly until the object appears as small as possible. You may notice faint stars suddenly appearing, just visible through the haze of sensor noise. This is a good indication that focus is nearly perfect.

And here's your pro tip for this

ALL IMAGES COURTESY OF THE AUTHOR

article: Be careful not to breathe on your camera's lens while making any adjustments. The warm, moist air you exhale might condense as dew on the front element of the lens, spoiling your images. (That's the voice of experience speaking here.)

Long-focal-length lenses often display mild *chromatic aberration* (color fringing) around bright stars. These halos will change from magenta to teal as you pass through the point of best focus. Ultimately, your goal is to minimize the size of the star and any associated color fringing. Sometimes the best setting is a compromise between a tiny star and one that's completely free of chromatic aberration.

Turbulence in the atmosphere can cause stars to appear to "twinkle," making it more difficult to evaluate your progress. In such conditions, avoid aiming near the horizon, where the twinkling effect is most extreme, and instead aim at a star near the zenith.

Open Wide

If you're working with the "kit" zoom lens your camera came with, consider upgrading to a fast *prime* (fixed-focal-length) lens with a wide aperture. Such lenses usually produce brighter images, which are easier to evaluate for sharpness. Keep in mind that each decrease in f/stop doubles the amount of light reaching the camera's sensor. For example, an f/1.4 lens gathers 16 times more light than one operating at f/5.6. (Turn to page 54 of the October 2022 issue for recommendations on upgrading your lens.)

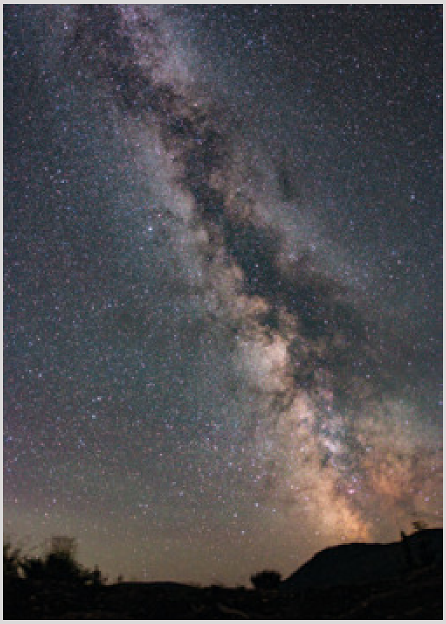
Fast primes aren't cheap, but they often feature better optics and mechanics that enable more precise focusing. Inexpensive lenses may exhibit a slight amount of image-shift as you rotate the focus ring back and forth, which turns makes the entire process more challenging. The *focus throw* (the amount you have to turn the focus ring to go from closest focus to infinity) will determine how precisely you can adjust the lens. High-quality models with longer focus throws are generally easier to focus. Of course, it's not impossible to achieve good results with a kit zoom — you just need to work a little bit harder.

Going Remote

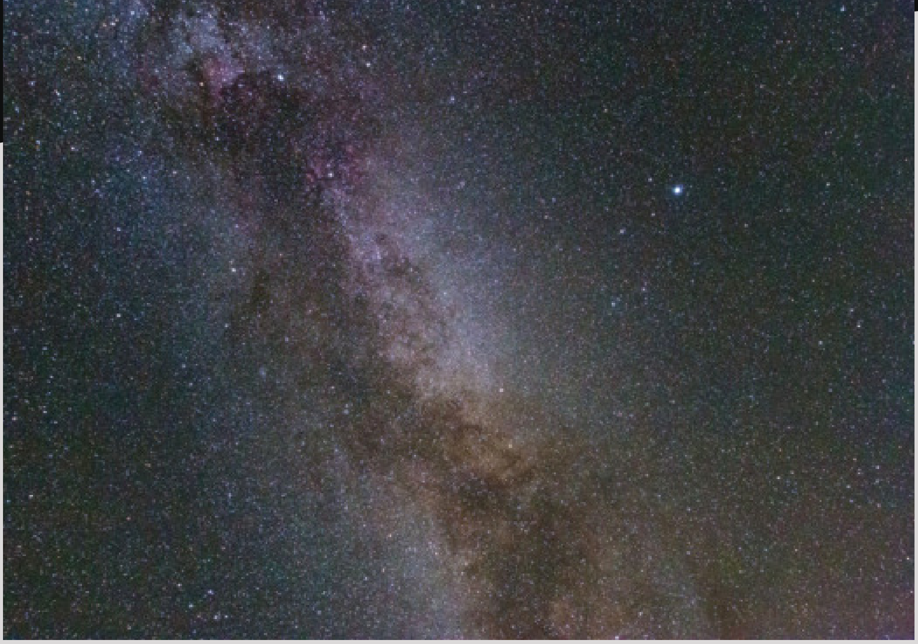
Even with a high-quality lens, the relatively small size of your camera's rear display will limit your ability to judge focus. Worse yet, if your camera lacks an articulated screen, you'll probably end up having to contort yourself into some weird and uncomfortable positions just to view it. This is especially true when shooting objects high overhead near the zenith.

▲ **BIG-SCREEN VIEW** The screen of an iPad tablet dwarfs the display of this Canon camera. Using Live View on a larger display makes obtaining perfect focus a snap, and since the connection is wireless the display can be positioned at a comfortable angle and away from the camera.

Luckily, many cameras are capable of wireless control, allowing you to take advantage of the larger screen on your mobile phone or tablet. For example, Canon's *Camera Connect* app allows Live View and focus with iOS and Android



▲ **MILKY SIGHTS** *Left:* This twilight view of the Milky Way was recorded in a 2-minute exposure made with a Canon 70D DSLR camera set to ISO 1600 and a 15-mm fisheye lens at f/2.8. Wide-angle optics such as this are perfect for beginning astrophotographers because such lenses are more forgiving of slight focus errors than longer focal lengths are. *Right:* Poor focus can be masked by low-quality optics, unsteady seeing conditions, or even passing clouds. That was the situation when this 2-minute exposure of the North America Nebula was made using an 85-mm lens.



▲ **SUMMER SWAN** Taking the time to properly focus the lens yielded pinpoint stars in this 2-minute, tracked exposure at ISO 3200 showing the Milky Way around the constellations Cygnus and Lyra. The author used his Canon 70D DSLR with a 22-mm lens at f/4.5.

devices. Some third-party applications, such as *Cascable* (iOS only) support multiple camera brands. Check your manual to see whether your camera is equipped with Wi-Fi and can take advantage of this handy feature.

Most digital cameras can connect to a laptop computer using a USB cable (also known as *tethering*). This allows you to use your computer's generous screen for focusing. Many manufacturers offer software specifically for this task. For example, Canon supplies a free application called *EOS Utility*, which allows you to display the camera's Live View feed on your computer screen. The software also lets you adjust autofocus lenses remotely, eliminating the need to touch your camera and introduce vibration.

The Bat Signal

Judging precise focus is much easier with a simple accessory called a *Bahtinov mask*, which attaches to the front of your lens. The mask is a thin, plastic disk that has a series of slots cut into it designed to produce a specific pattern of diffraction spikes around bright stars. By observing the position of the overlapping spikes, it's easy to determine the point of perfect focus.

The mask works extremely well with telephoto lenses but isn't very effective with wide-angle models owing to the tiny size of the resulting diffraction patterns. Bahtinov masks are available in various sizes from commercial sources, and you can even make your own if you're so inclined. They can be 3D-printed or simply cut from a sheet of black plastic. If you search online for "Bahtinov mask template" you'll find several options.

Finally, achieving sharp focus is one thing, but maintaining it throughout an entire imaging session is another. As your lens cools during the night, thermal contraction may cause the focus point to shift slightly. Also, some inexpensive lenses exhibit *focus creep* arising from mechanical components shifting slightly when the camera is pointed skyward. Even aiming at a different part of the sky runs the risk of introducing focus creep. That's why it's important to recheck focus occasionally throughout an imaging session.

As with so many aspects of night-sky photography, producing attractive images with pinpoint stars requires attention to detail. Don't be discouraged if you initially find yourself spending a lot of time focusing and less time shooting. The process will become faster and easier over time. And the reward is an image you'll be proud to call your own.

■ **TONY PUERZER** is a retired professional photographer focusing on leading a simple life on Vancouver Island in British Columbia, Canada.

▲ **MASKING FOR FOCUS** *Left:* The author uses this Bahtinov mask from Farpoint Astro with his 300-mm telephoto lens. The mask installs much like a standard lens filter and allows for precise focusing. *Right:* This pair of images illustrates how to focus a lens fitted with a Bahtinov mask. When the central diffraction spike is positioned exactly halfway between the two diagonal spikes (far right image), the lens is perfectly focused.

The Hickson Catalog's Deep End

These compact galaxy groups make for pleasing, but challenging, views in the eyepiece.

When Canadian astronomer Paul Hickson published his survey of compact galaxy groups in 1982, he was driven by his interest in their dynamical peculiarities and their role in galaxy evolution. Before the century was out, however, he found himself a sought-after guest and lecturer among amateur astronomers who gathered with their telescopes under dark skies to observe his groups visually. Amateurs' interest in Hickson's catalog was emblematic of the new direction the hobby was taking as scientific information and large-aperture telescopes were becoming more accessible.

Visual observers have since pursued other galaxy groups, such as those in catalogs that American astronomer James Rose or Armenian astronomer Romelia Shakhbazian assembled. Yet the 100 Hickson groups remain the most popular. The more frequently observed Hicksons comprise, or at least are anchored by, galaxies from the *New General Catalogue of Nebulae and Clusters of Stars*, which are comparatively bright. We have previously highlighted some of these brighter groups (see, e.g., *S&T:* Nov. 2017, p. 34). The typical Hickson group, however, contains no NGC galaxies at all.

As I'm completing my visual survey of the Hickson catalog, the faintest members of quite a few groups still elude me, even though I have access to very dark mountain skies and a 20-inch scope. To decide if you are up for jumping into this catalog's deep end, try the following selection of targets well placed in the April sky and see if they whet your appetite for further pursuit.

Dipping Our Toes

Transiting near the zenith in the early evening is **Hickson Compact Group 36** in Cancer. Look for HCG 36 some 6.3° east-southeast of Delta (δ) Cancri. This group is anchored by the relatively large and bright 14.1-magnitude, 1.5′-long galaxy IC 528. The companions, however, are from the *Catalogue of Principal Galaxies*. The galaxies of HCG 36 are all spirals, and each displays a different inclination to our line of sight. After tracking down this group with the 20-inch telescope of the Buffalo Astronomical Association observatory under rural skies, I detected all four members at 450×. Components of a Hickson group are referred to by letter designations, which usually run from A through D in order of brightness. HCG 36's easternmost component, HCG 36D, displayed its elongated form, as did the dominant central galaxy, HCG 36A (IC 528). The latter, however, appeared to terminate south of HCG 36C, indicating that I was only seeing its inner core. In the case of the southernmost component, HCG 36B, which is a nearly edge-on spiral, I only noted the compact central core. Subsequently, observing with my own 20-inch from a much darker location, I

▼**GRACEFUL GROUPINGS** You'll need a big telescope and dark skies to observe the galaxy groups outlined here. But if you succeed, you'll be well rewarded by having stepped up to the challenge. We've used Hickson's original lowercase labeling for the components in the images presented here.

ALL IMAGES POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; ALL SKETCHES IVAN MALY

DIGGING DEEP Use these images as finders to guide you to each HCG target. Letter designations are from Hickson's 1993 catalog. Dimensions are indicated in each.

A SEXTET OF GALAXY GROUPS The author sketched the targets outlined here at the eyepiece of his 20-inch telescope. (Magnifications and fields of view are indicated.)

could also see a 16th-magnitude galaxy (SDSSCGB 51371.3) off the western edge of IC 528. While Hickson didn't include it in HCG 36, its redshift indicates that it is indeed a member of the same group.

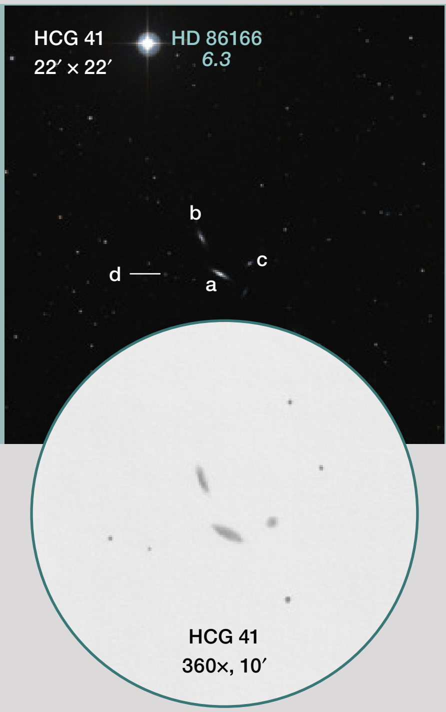
The galaxy-rich constellations that transit around midnight in April are a treasure trove of intriguing Hickson targets. To start with, **HCG 39** in Hydra may well be the most difficult group in the catalog to resolve into individual galaxies. HCG 39 lies a bit more than 2½° west of 3.9-magnitude Iota (ι) Hydrae and 8′ southeast of 6.3-magnitude HD 81980. A magnification of 570× wasn't enough for me to resolve components A, B, and C into anything other than a nearly 1′-long streak resembling a flat, edge-on galaxy. Component D, 20″ off the chain's northwestern end, was cleanly separated with the same magnification. Curiously, I noted that the galaxy next to the star that lies 2′ southeast of the group was not visible, although photographically it appears at least as prominent as HCG 39D. On the night of my observation, I recorded poor seeing, which undoubtedly didn't help the task of separating the group's galaxies. Unsteady seeing frequently accompanies the kind of excellent transparency that we had that night — a trade-off that will often limit your ability to observe faint Hicksons, unless you have access to professional-quality astronomical locations.

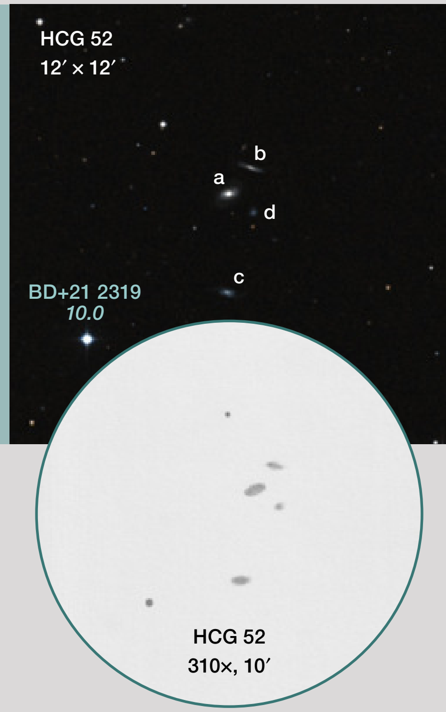
Next, head over to Ursa Major, where you'll find **HCG 41** around 4.2° northwest of 3.5-magnitude Lambda (λ) Ursae Majoris, or Tania Borealis, the Bear's hind toe. A 6.3-magnitude star (HD 86166) stands guard some 11′ north-northeast. It's a beautiful little collection of three edge-on spirals and one lenticular. The central clustering of three galaxies (A to C) is followed by the smallest group member, D, to the east. Photographs show an additional edge-on galaxy just southwest of the group. Under excellent conditions at my remote observing site and with 360×, I couldn't detect the non-member galaxy, while HCG 41D looked like a soft image of a threshold star. I did, however, observe components A through C, with their individual extents and orientations. There are few sights in the universe that, to my eye, match the dynamism of a galaxy group seemingly flying in all directions. HCG 41 presents an excellent example of this appearance — even though it's tiny and faint. From a distance of roughly 400 million light-years, only HCG 41A is brighter than magnitude 15 and exceeds 1′ in size. In this instance, the impression of the objects flying apart has something to do with reality: The galaxies have widely different redshifts and, as Hickson noted in his 1993 opus, must be physically unrelated.

Diving Deeper

So, can one actually see any gravitationally induced structural features in a Hickson group? The answer is a cautious "yes," so long as your expectations are tempered. Take, for example, **HCG 47** in Leo, which you'll find a bit more than 4½° east-northeast of Regulus and 1.6° west-southwest of 5.5-magnitude 46 Leonis. It consists mostly of small, featureless *Morphological Catalogue of Galaxies* members. Component A, however, is 13th-magnitude UGC 5644, a nearly face-on spiral with two arms that are visible in photographs. I see the western arm as much brighter and extending toward HCG 47B, which suggests gravitational interaction to me. At 450×, I was able to see a clear trace of this arm even under the rural skies of the Buffalo club's observatory. In fact, I noted that this arm segment seemed more prominent than the galaxy's core, resulting in a very asymmetrical appearance. As expected, component B is the second-brightest member of this group. Another close galaxy pair, comprising members C and D, is immediately to the north. HCG 47D appears larger, but HCG 47C sports the brighter nucleus.

HCG 49 is our northernmost target — look for it some 5½° north-northwest





of Alpha (α) Ursae Majoris, or Dubhe, in the Big Dipper. A magnification of 360× readily showed me HCG 49A and HCG 49B, as well as elongation in the former. I could only detect HCG 49D with effort, and HCG 49C not at all. Upping the magnification to 570× revealed elongation in B and the small, round form of C next to it. HCG 49D, however, remained small and amorphous even at that magnification. I spotted a 16th-magnitude star immediately south of the group. The galaxies' visual appearances are consistent with their morphological classification: Components A and B are evolved spirals, C is an irregular galaxy, and D is an elliptical.

Let's end our excursion in Leo with another fine example of a gathering of galaxies, **HCG 52**. You'll find it a tad less than 3° east-northeast of 2.5-magnitude Delta (δ) Leonis, or Zosma. Three of the four galaxies in the group are strongly inclined to our line of sight. HCG 52A is a barred spiral, and I observed only the inner part of it at 190× and 310× with our observatory telescope. I couldn't resolve the features that are evident in photographs, such as the bar and a surrounding ring. HCG 52B appeared much broader than the needlelike silhouette that appears in images — a common visual effect when observing edge-on galaxies on the threshold of detection. In these conditions, I only noted the inner core of HCG 52C, with no hint of its "garden sprinkler" arms. HCG 52D is a round puff, barely larger than a star image but lacking any sharp concentration toward the middle. Indeed, if you detect component D at all, you can congratulate yourself on seeing about as much as the best digital survey images reveal in this tiny (a mere 20″ in diameter) 17th-magnitude galaxy.

Denser and better outlined than typical galaxy clusters, compact galaxy groups are among the largest cohesive structures that we can see with our own eyes. Observing all the Hickson groups has remained a challenging undertaking for visual observers with big telescopes. Once you start checking Hicksons off your list, however, you may not be able to put that list down.

■ **IVAN MALY** is a biologist living in upstate New York. His observing website is at **www.deepskyblog.net**.

FURTHER READING: Hickson's original 1982 catalog is at **https://is.gd/Hickson_Catalog** and his follow-up work at **https://is.gd/Hickson_Atlas_1993**.

Hickson Compact Groups

Object	Anchor Galaxy	Mag (Tot)	Size	RA	Dec
HCG 36	IC 528	12.5	1.9′	$09^h\ 09.4^m$	+15° 48′
HCG 39	UGC 5057	13.9	1.0′	$09^h\ 29.5^m$	–01° 21′
HCG 41	UGC 5345	11.9	4.1′	$09^h\ 57.7^m$	+45° 14′
HCG 47	UGC 5644	12.5	2.3′	$10^h\ 25.8^m$	+13° 44′
HCG 49	PGC 32899	14.4	0.9′	$10^h\ 56.6^m$	+67° 11′
HCG 52	PGC 35183	12.8	3.2′	$11^h\ 26.3^m$	+21° 05′

The magnitudes are total for each group. Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Gossamer Winds

While every total solar eclipse is different, past performance can help you plan for your next encounter with totality.

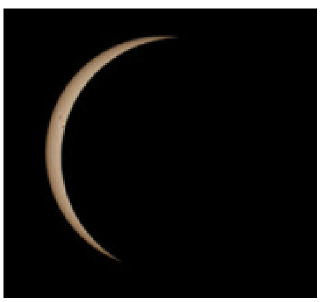
Slightly more than 5½ years have passed since the Moon's shadow cut a swath across the United States. Likely the most viewed total solar eclipse in history, the 2017 event is about to be matched and even bested on April 8, 2024, when totality races across the globe from the South Pacific Ocean, crossing Mexico, the United States, and parts of eastern Canada before ending in the Atlantic, off the coast of Europe.

The article on page 26 details what locations are best suited to viewing totality. But what will the eclipse look like? Because the Sun's outermost atmosphere, the *corona*, is influenced by magnetic fields within our star, it can be hard to predict what we'll see in 2024 with anything more than generalities. For example, the recent eclipses of 2017 and 2019 occurred as the Sun was near solar minimum when sunspot activity was weak, and coronal streamers were primarily confined to the solar equator. But activity has been on the rise since 2020 — more sunspots are appearing, forming closer to the solar poles, which mark the points where magnetic fields penetrate the solar surface. And more of these sunspots means a busier corona. As a result, those loops and streamers have been more numerous and migrating closer to the polar regions, as seen in the 2020 and 2021 total solar eclipses.

By the time of next April's event, the Sun will be nearing peak activity for Solar Cycle 25, so we can expect that the Moon's silhouette will be surrounded by numerous coronal streamers and prominences going off in every direction.

Now's the time to start planning how you'll photograph this eclipse. Our selection of recent eclipse images showcases how several photographers captured their brief encounter with the lunar shadow to great effect. Perhaps these vignettes will help you determine how you'll record your own keepsake of this remarkable event.

▲ **MORE THAN MEETS THE EYE** This detailed, high-dynamic-range composite image of the August 2017 eclipse was processed to reveal loops and streamers in the corona as well as the lunar surface and several background stars. For this picture, Nicolas Lefaudeux combined 70 exposures ranging from 1⁄250 to 5 seconds using a 100-mm Sky-Watcher refractor and a Sony A7R II camera.

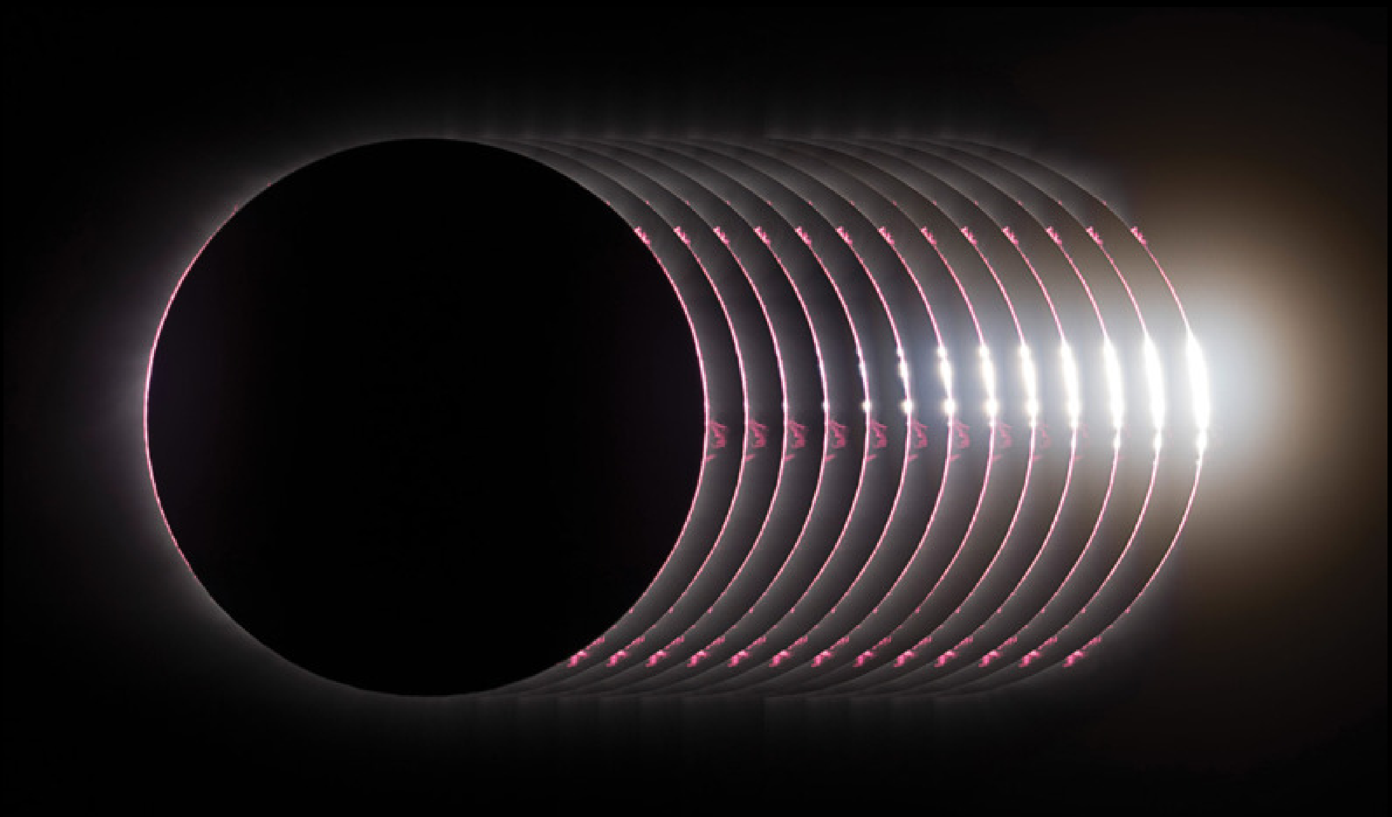


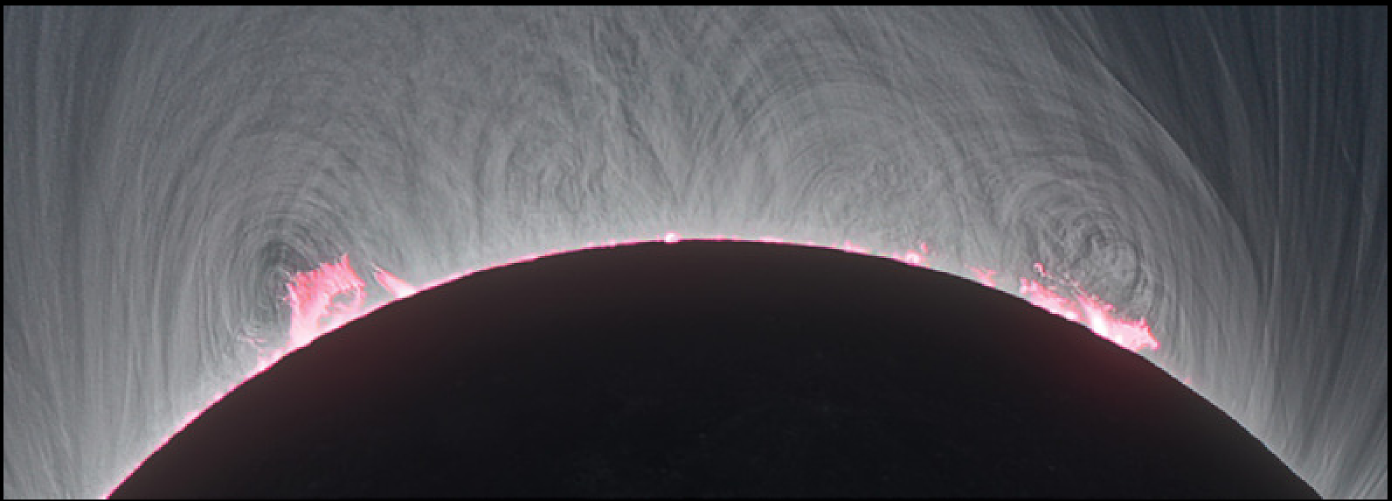
▶ **ALMOST, BUT NOT QUITE** Partial phases during a total solar eclipse are the only thing observers see if they're located outside the path of totality.

NICOLAS LEFAUDEUX (2)

■ Associate Editor **SEAN WALKER** has witnessed totality twice so far and hopes to luck out a third time in 2024.

AWESTRUCK Rogelio Bernal Andreo photographed the 2017 eclipse from Phillips Lake, Oregon, using a wide-angle lens. Moments before the start of totality, another witness waded into the lake, allowing Andreo to capture the wonder and mystery of the eclipse in this composition. He used a Canon EOS 5D Mark II with a Rokinon 24-mm lens to create this two-panel mosaic, each half exposed for 2 seconds.

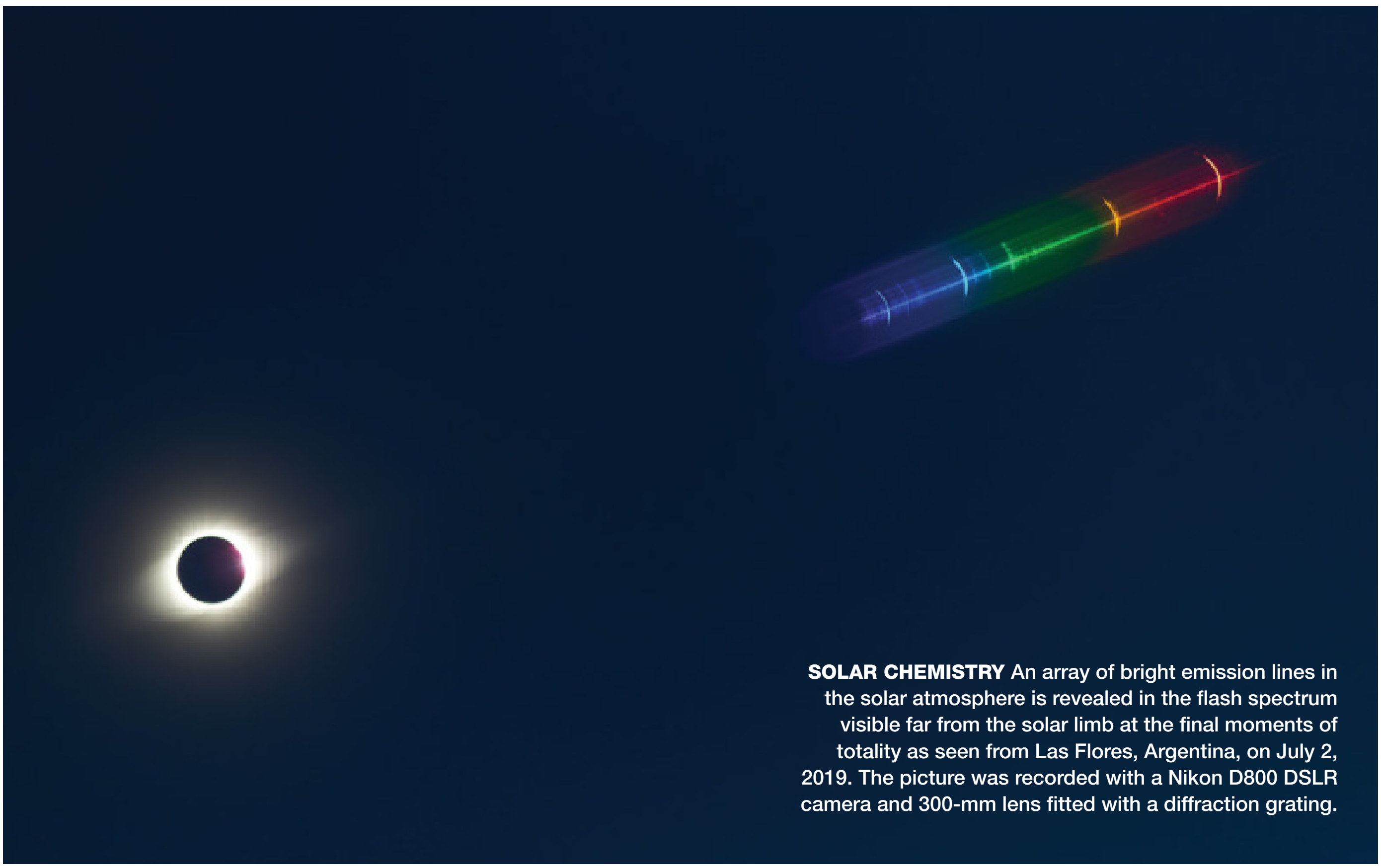




▲ **UNFILTERED LIMB** Several blazing solar prominences were visible along the Moon's silhouette moments before third contact during the 2017 eclipse. Totality is the only time prominences are visible without protective filters and reveal their pinkish color. Nicolas Lefaudeux used the same telescope camera and compositing technique to produce this image as he used for the one seen on the top of page 60.

▲▲ **GLITTERING BEADS** A rapid series of short exposures permitted Fred Espenak to catch Baily's Beads — parts of the solar disk seen between the Moon's crater rims and mountains as the Sun emerged during third contact. The image is a montage of 13 exposures of 1⁄1000 second at ISO 200 taken with a Nikon D810 DSLR camera and 1,000-mm lens at f/10.

OUT OF THE SHADOWS Long exposures reveal details on the lunar disk often overwhelmed by the beauty (and brightness) of the corona during a total solar eclipse. This image is a single 2½-second exposure recorded through a 90-mm Vixen refractor during the July 2, 2019 eclipse from Vicuña, Chile.



SOLAR CHEMISTRY An array of bright emission lines in the solar atmosphere is revealed in the flash spectrum visible far from the solar limb at the final moments of totality as seen from Las Flores, Argentina, on July 2, 2019. The picture was recorded with a Nikon D800 DSLR camera and 300-mm lens fitted with a diffraction grating.

EARTHSHINE: FRED ESPENAK; FLASH SPECTRUM: ROBERT SLOBINS

ZWO's AM5 Strain-Wave Mount

This growing camera manufacturer makes its first foray into the realm of telescope mounts. How does it perform?

◀ ZWO's new AM5 mount shown carrying the author's 71-mm William Optics refractor and several additional ZWO imaging accessories. The optional PE160 pier extension raises the mount 16 centimeters (6.3 inches) from the tripod.

ZWO AM5 Harmonic Equatorial Mount

U.S. Price: $1,999 mount
$349 for the optional TC40 Carbon Fiber Tripod
astronomy-imaging-camera.com

What We Like

Extremely portable

No motor backlash

What We Don't Like

Large periodic error

No power supply or cable included.

WALK AROUND ANY amateur gathering at night where astrophotographers are at work and you'll see lots of red, and I'm not just talking about red headlamps and computer screens. Imaging cameras and peripherals by Chinese manufacturer ZWO are very popular these days, and their red anodized finish defines the company's product lines.

With 11 years of success producing quality planetary and deep-sky imaging cameras, ZWO recently expanded into the realm of focusers and minicomputers with integrated equipment control (*S&T:* May 2022, p. 66). So it's perfectly logical that its next step would be to expand its imaging offerings. The introduction of the AM5 Harmonic Equatorial Mount is that next step, and, yes, it sports a sleek red finish.

I tested the AM5 mount for several months using my own ZWO cameras and several of the company's other imaging devices.

A Powerful Block

The compact AM5 mount incorporates *strain-wave drive systems* on both axes. These drives use high-torque gear systems that eliminate backlash. And depending on the telescope load, the AM5 can even operate just fine without counterweights. It's maximum weight capacity is 20 kilograms (44 pounds).

The mount's squarish housing contains all the motors and electronics. The telescope-mounting saddle stands 4.4 centimeters (1¾ inches) from the housing, allowing the AM5 to track as much as 20° past the meridian. It can operate in both equatorial or alt-azimuth mode.

A soft case is included with foam cutouts for the mount head, two metric hex wrenches, the hand controller, and 2-meter USB cable. There's also a space for a counterweight shaft (provided for the review but an optional $39 purchase).

After some minor indoor assembly, setting up the AM5 on the optional TC40 Carbon Fiber Tripod is quick and easy. You connect the tripod's circular mounting flange to the bottom of the mount base with three screws. The flange then drops into the tripod's mounting collar, where it's secured by tightening a lever. You can rotate the head in azimuth to roughly point the mount north before locking it into position. This flange then

▶ The included zippered case uses high-density foam to protect the mount head and additional accessories. The tripod mounting flange is seen attached to the AM5 base. The optional stainless-steel counterweight shaft is also shown.

ALL PHOTOS COURTESY THE AUTHOR

remains attached even when the mount is returned to its case.

The mount and tripod stand just 0.8 meters with the tripod legs fully extended — a bit low for use with some refractors and catadioptric scopes. With its legs retracted, the TC40 measures about half a meter. ZWO also offers 160-mm, 200-mm, and stackable 70-mm tripod extensions to raise scopes to a more comfortable height.

The tripod's carbon-fiber legs make it extremely lightweight (just 2.3 kg). Two included items help provide increased stability when using the AM5 with heavy payloads. First, there are three steel spikes that replace the tripod's rounded rubber feet. These spikes dig into the ground and help anchor the tripod legs securely. The other accessory is a triangular weight bag suspended between the tripod legs with Velcro fasteners. Small weights can be placed in the bag to provide additional stability. I used this feature whenever I had scopes larger than 4 inches on the mount, but my 71-mm refractor worked fine without the weight bag, allowing me to carry the fully assembled setup outside for imaging sessions.

You can power the AM5 with a wide range of 12V DC power supplies that deliver 5 amps. Although no power cable is included with the mount, a 12-volt, 5-amp AC inverter I had on hand worked flawlessly, as did a 12-volt, deep-cycle marine battery.

Polar aligning the AM5 can be straightforward or time-consuming depending on whether the user has an ASIair unit. The mount doesn't have a polar-alignment scope or even a simple sight tube for viewing Polaris. Polar alignment is best achieved using the routine with the ASIair. The procedure, done from within the *ASIAIR* app, involves *plate-solving* (identifying known star patterns) in several short exposures recorded through your telescope with an imaging camera, then adjusting the mount's altitude and azimuth motions as directed. The alignment star field doesn't need to be near the pole, either — any part of the sky except due east and west will work. That makes accurate polar alignment easy even when you have set up without a clear view of the celestial pole. Polar alignment without the ASIair can be done using the star-drift method.

Although a mounting shoe is provided on the side of the AM5 housing intended for an ASIair or a small polar finder on a standard quick-release bracket, I preferred mounting the ASIair directly on the tube of my telescopes because that location provides a minimum of cables running to the mount that could snag during slews or tracking.

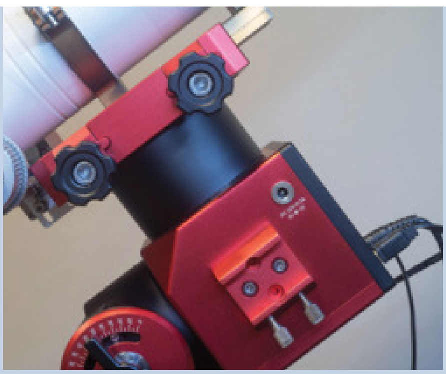
◀ The small hand controller for the AM5 is used for manual slewing and speed adjustments. All Go To functions are handled within the *ASI Mount* app.

The AM5 saddle accepts both Vixen-style dovetail bars and the wider Losmandy-style mounting bars. Two locking jaws with large knobs ensure any telescope riding on the AM5 is securely held in place.

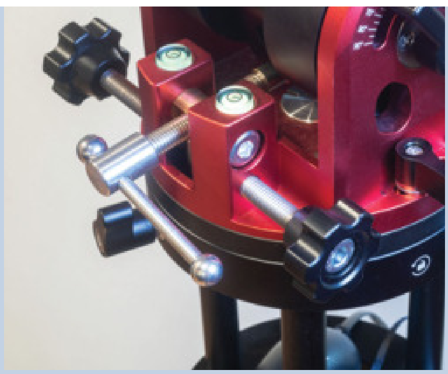
"Weightless" with the AM5

One of the attractive features of the AM5 with its strain-wave gearing is that given the motors' extreme rigidity and high torque, they can drive payloads up to 13 kg without adding any counterweights.

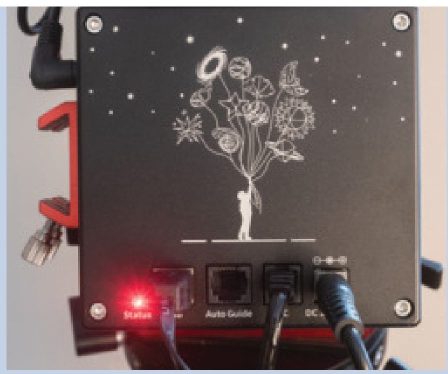
Like other strain-wave-driven mounts, you can forget about loosening clutches to balance the scope. The only way either axis can be adjusted is with the hand controller or computer



▲ The generous space between the saddle and the declination housing allows the AM5 to track up to 20° past the meridian, depending on the specific telescope attached. The two saddle clamping knobs make tightening the saddle clamps easy. A mounting shoe for the company's ASIair controllers is attached to this side of the housing. Also visible is a 12-volt, 3-amp power output socket.



▲ The polar-axis controls and locking levers on the AM5 are large and easy to grip. Note the latitude is adjustable from 0 to 90 degrees, permitting the mount to be used in either alt-azimuth or equatorial modes.



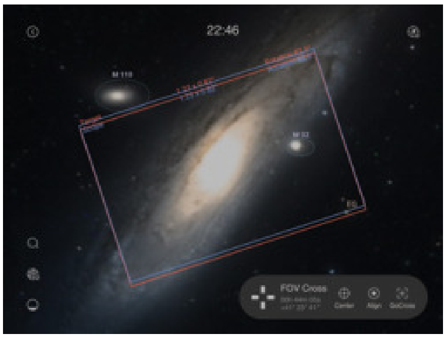
▲ Along with a whimsical graphic, the pole-facing side of the AM5 contains a USB computer connection, ST-4-style Auto Guide port, hand controller (HC) input, and power input port (though the mount does not include a power cable). The LED at left shines steady red when the mount is powered up in equatorial mode, or green in alt-azimuth mode.

control. This makes accurate balance of the attached gear difficult.

Still, I determined the balance point on each of my OTA setups by placing them on a pencil on a flat surface. I would then slide the mounting bar and its balance point to the middle of the AM5 saddle.

An optional 23-cm steel counterweight shaft is recommended for larger payloads, though at this time ZWO doesn't offer any counterweights. However, you can use any counterweight with a central hole large enough to fit over the 20-mm diameter shaft.

I used my own 5-kg counterweight with my heavier telescopes, including a Celestron RASA 8 and an Astro-Tech 8-inch Ritchey-Chrétien (RC). To test stability, I set up the AM5 with the RC both with and without a counterweight — there was no change in tracking or guiding performance. The strain-wave drives didn't seem to care.



To really give the mount a workout, I loaded up my Celestron 11-inch SCT with its imaging accessories (seen on the facing page). Despite approaching the mount's recommended weight capacity, it still tracked quite well, though it was very sensitive to wind, and the single counterweight was inadequate to properly counterbalance the telescope. ZWO doesn't recommend using any more than a single 5-kg counterweight.

In practice, loads of around 10 kg or more without counterweights caused the tripod to flex, particularly when pointing near the meridian. And a flexing tripod can lead to changes in polar alignment, which could affect imaging results. The mount's base includes a central, ⅜-inch threaded hole in the bottom — an industry standard that allows the AM5 to connect to a wide range of heavy-duty tripods. Flexure wasn't a problem when the AM5 was mounted on a permanent pier in my yard.

Periodic Error

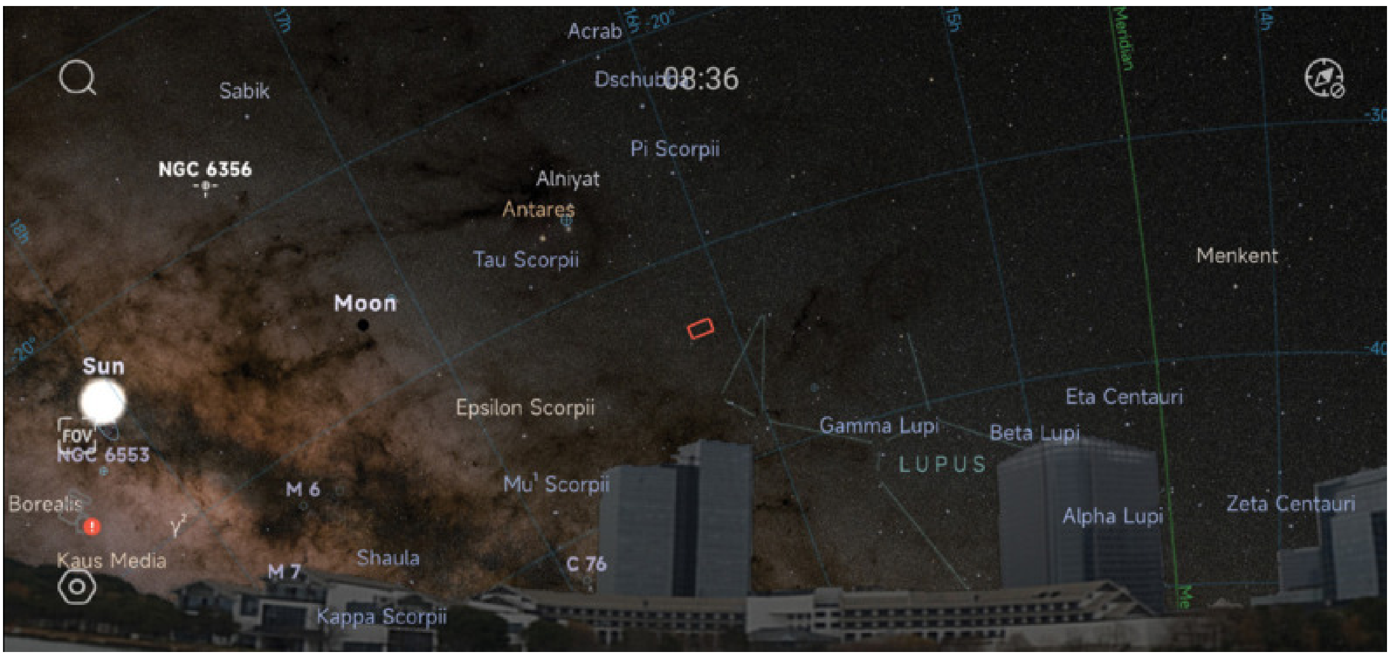
The AM5's strain-wave gearing on both axes gives the mount a solid feel, with no backlash on either axis whatsoever. That same gear system produces some periodic error — a recurring inconsistency in tracking speed that makes active guiding essential.

I measured the periodic error (PE) on the AM5 to be about 20 arcseconds, which matched the graph provided by the manufacturer with the mount. This considerable PE was easy for all of my autoguiders to correct. Regardless of which telescopes I used, autoguiding with guidescopes or an off-axis guider consistently averaged about 1 arcsecond in total error — smaller than what would show in my images.

Nearly every unguided exposure up to one minute with my 8-inch Celestron Rowe-Ackermann Schmidt-Astrograph and its 400-mm focal length showed round stars. Anything longer required additional autoguiding.

Unconventional Control

The AM5 hand controller is unusual, to say the least. It lacks a keypad, screen, or readout panel of any kind — it's just a small, palm-sized device with a pair of buttons and a thumb-operated joystick. Accessing the target database is the job



▲ *Above:* The *ASI Mount* control app displays a realistic view of the Milky Way, with good detail as you zoom closer in. *Above left:* The app provides a customizable field-of-view indicator to help users frame their targets, like this example showing M31 framed and oriented for the author's ASI2600MC-PRO camera and 8-inch RC telescope.

of the free *ASI Mount* app (or the *ASIAIR* app if you are using an ASIair device), downloadable from the iOS Marketplace or Google Play store. The *ASI Mount* app links your smart device to the AM5 through the mount's built-in Wi-Fi and is also used to update the mount's firmware when necessary.

The joystick moves the mount in both axes. Pressing the T button on the hand control starts the mount tracking, while pressing it again stops it. Momentarily pressing down on the joystick enables the mount's fastest slew speed of 6° per second. The other button instantly stops the slewing in the event of a cable snag or to prevent a scope from colliding with the tripod. Pressing and holding the same button for 3 seconds sends the mount to its home position. The AM5's hand controller includes an internal Wi-Fi antenna, so the mount only has Wi-Fi capability with the hand controller connected.

The real controller for the AM5 is the *ASI Mount* app, or, as noted earlier, the *ASIAIR* app for users with the device.

▲ *Left:* The AM5 mount can carry lightweight OTAs without counterweights, but heavier loads like the author's Astro-Tech 8-inch f/8 Ritchey-Chrétien astrograph required a counterweight shaft and an additional counterweight. Without these, the optional TC40 tripod flexed under heavy loads, which throws off polar alignment and reduced the AM5's pointing accuracy. *Right:* This Celestron C11 loaded with imaging accessories was under the AM5's 20-kilogram weight limit when using a counterweight but exceeded the recommended OTA length for the mount.

This photo of the Horsehead Nebula (IC 434) was imaged with a William Optics 71-mm refractor and ZWO ASI2600MC-Pro camera riding atop the AM5.

The mount control app includes a planetarium program that uses the open source Stellarium Web Engine to render a pleasing simulation of the night sky. When first launched, users are prompted to input location information, as well as additional details such as the telescope's focal length, camera model (or the sensor dimensions for non-ZWO cameras), and its rotation angle to help you frame the object in the camera's field.

The *ASI Mount* app contains a database of roughly 20,000 objects. Touching the magnifier icon at the top left of the screen opens a listing of targets visible as "Tonight's Best" and includes the Sun, Moon, and planets, current comets, and many deep-sky objects from lists, including the Messier, NGC, IC, Sharpless, and Caldwell catalogs. This list also offers helpful information, including a graph of the objects' altitude throughout the night. Pairing the mount with an ASIair computer and its control app opens up a much larger database, and that's really the best option for imagers, particularly those using the company's cameras and other accessories.

The AM5 is ASCOM-compatible and uses the LX200 protocol, permitting it to be controlled by most desktop planetarium programs that include mount control through its USB connection.

The Bottom Line

The ZWO AM5 Harmonic Equatorial Mount represents a milestone in equatorial-mount design, build quality, and astro-imaging control at an attractive price. Its rigid, zero-backlash drives and accurate Go To pointing are all highly desirable, time-saving features particularly for imagers. For users with cameras and accessories by other manufacturers, the list of conveniences with the AM5 is somewhat shorter (polar alignment is a much lengthier, manual process), but the mount works just like any conventional computerized mount.

If you're in the market for a high-performance and highly portable Go To equatorial mount for imaging and already own ZWO cameras and an ASIair device, this mount should be near the top of your list.

■ Contributing Editor **JOHNNY HORNE** has slowly turned his imaging equipment red with new purchases.

▲ *Left:* Emission nebulae IC 405 (top) and IC 410 (bottom) were recorded with a Celestron RASA 8 and ASI2600MC-Pro while an ASIair Plus with its *ASIAIR* app controlled the AM5 mount as well as the camera, guider, and focuser. *Right:* The bright stars of the Pleiades, including Maia (top right), Alcyone (upper left), and Merope (right), are surrounded by nebulosity in this photo tracked and guided with the AM5 Mount. Thirty-seven 5-minute exposures were stacked for this image using an Astro-Tech 8-inch f/8 Ritchey-Chrétien telescope and ASI2600MC-Pro camera operating at f/5.6.

◀ PLANETARY CAMERA

QHYCCD announces a new camera model for planetary imaging and autoguiding. The QHY5III200M ($309) is designed around the Sony SC2210 back-illuminated CMOS sensor, which has a 1,920 × 1,080 array of 4-micron-square pixels. Its body is designed to fit directly in any 1¼-inch focuser and requires just 8 mm of back focus. The camera can download 96 frames per second at full resolution in 8-bit mode, and up to 209 fps when using a region-of-interest (ROI) crop. An internal, 512-megabyte DDR3 image buffer ensures no frames are dropped during downloads. The QHY5III200M also functions as an autoguider and connects to your telescope mount via an ST-4-compatible guide port. Each purchase includes a 1.5-meter USB 3.2 Type-C cable, a 2-meter guiding cable, an IR850 filter, and a CD with camera drivers and control software.

QHYCCD
503, Block A, Singularity Center, Shahe Town, Changping District, Beijing, China 102206
+86(10)-80709022-602; qhyccd.com

◀ MOUNTING SHOE

Orion Telescopes & Binoculars adds the Universal Dovetail Finder Scope Base to its extensive line of accessories for backyard astronomers. This $29.95 dovetail shoe can be installed on any tube assembly with a diameter of 100 mm or more. It accepts most removable Orion finderscopes, mini guide scopes, and reflex sight brackets, as well as many third-party finders that follow the same standard format. Its two pairs of perpendicular slots will fit screw-hole spacing between 14 mm and 39 mm and can be mounted at any convenient location on your telescope. Two nylon-tipped thumbscrews secure your finder without marring its finish and are easy to grasp even while wearing gloves. The base includes two 16-mm-long M4 stainless-steel Phillips machine screws and matching hex nuts.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

◀ BEEFY MOUNT

Sky-Watcher USA adds a new model to its line of equatorial telescope mounts. The CQ350 ($3,500) is a Go To mount designed to better position its weight directly over its center of gravity. The mount features whisper-quiet dual belt drives combined with hybrid stepper-motors that provide increased accuracy when slewing and guiding. The mount head weighs 24 kilograms (53 pounds) and can bear an instrument load of 35 kg not including the counterweights. Its dual-format saddle accepts both Losmandy-D and Vixen-style dovetail mounting bars. The CQ350 includes an integrated cable-management system with four USB 3.0 ports, three 2.1-mm power ports, and several auxiliary ports to prevent cable snags during operation. The mount is controlled with Sky-Watcher's upgradable SynScan Go To hand paddle that includes a database of more than 42,000 objects. Each mount ships with two 22-lb counterweights. The CQ350 is also available paired with a heavy-duty steel field tripod ($4,265), and an illuminated polar-alignment scope can be added at additional cost.

Sky-Watcher USA
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.

Roll-off the Whole Building

Try this simpler solution for a home observatory.

AFTER AN AMATEUR ASTRONOMER has been observing for a while, setting up their telescope each night and tearing it back down in the wee hours, their mind often turns to building a permanent observatory. One of the most common types is the shed with a roll-off roof, wherein the top of the building slides on rails onto a support structure at the end of the building, leaving the sky open for astronomy.

Not surprisingly, rolling off the roof leads to several difficulties. First off, the building needs to be custom-made with a detachable roof. The outside support structure has to be strong enough to hold that roof, which means a pretty robust framework that's equal in size to the building. Then there's sealing it against the elements and against intrusive creatures while it's closed. And when the roof is moved away, you still have walls that block your view down to a point significantly above the horizon.

California ATM Laird Stiegler decided to solve all those problems in one fell swoop, by leaving the roof intact and rolling the *entire building* away. Doing so meant he could use a commercially available storage shed, one that was considerably cheaper than a custom-built shed and already designed to be tight against vermin.

Moving an entire building is not without its own challenges, but those challenges are comfortably low to the ground. Wheels at the corners roll on U-channel tracks that can lie on the surface or even be recessed below ground level where they aren't a trip hazard. If the telescope within is to be permanently mounted, as Laird's 14-inch Celestron Schmidt-Cassegrain is, then the building needs to slide around the pier, which means cutting a slot in the floor. That weakens the floor, so it needs to be reinforced.

Laird solved that problem by setting his building on a hefty platform made of crisscrossed 2″ × 10″ lumber. He added a set of wheels directly beside the cutout, so they offer additional support in the center. Laird reports that he can stand right next to the pier cutout and not see any sag to the floor at all. The cutout piece is modified to fit back in place when the building is rolled over the scope, sealing tight around the pier and against the rest of the floor and the door.

The rollers are on fixed axles rather than swivel castors. The building is only rolling out and back, so fixed axles work much better. Laird can push the entire works with one hand. Its easy movement would be problematic in a windstorm, except the trapped pier holds the building from moving when it's buttoned up, and you don't observe in high winds anyway. For added security, however, Laird added tie-down straps at the corners. The structure is far less likely to move than a lightweight roll-off roof.

The observatory rolls to the north, leaving the east, south, and west wide open for observing. It can be pushed far enough away to allow polar alignment or moved closer to provide a windbreak on breezy nights. Its interior has plenty of room for shelves, so Laird keeps all his accessories inside where they stay dry. The structure's large doors allow easy access, so it's at least as convenient

ALL IMAGES COURTESY OF LAIRD STIEGLER

▲ *Left:* When closed, Laird Stiegler's observatory is just a commercial storage shed on a wheeled platform. *Right:* The entire building rolls away, leaving the telescope on its pier with a view down to the horizon on three sides.

▲ The floor is cut out to accommodate the telescope pier. A removable section seals the slot tight against intrusive creatures. The section to the right is a brace that goes under the sill.

▲ The building rests on a framework of criss-crossed 2″ × 10″ lumber.

as working out of the back of a car. Plus, there's room for Laird and his guests to step inside and warm up on cold nights.

Since the floor moves away with the building, Laird laid down an observing platform of concrete pavers, then covered it with indoor-outdoor carpet for added comfort. His California climate is dry enough that he doesn't need to remove the carpet between observing sessions, although that would be easy enough to do in wetter climes.

During the day, the north side of the building is perfectly usable space in his friend Manny's yard. Two rails mark the wheels' path, but there's no overhead structure to contend with and no posts to get in the way of lawnmowers or other encroachments. By day it's just a storage shed in the yard, but by night it's a fully functional and very convenient observatory.

For more information, contact Laird at **jupitermars8@yahoo.com**.

■ Contributing Editor **JERRY OLTION** is searching for a good site to build his own observatory.

Going Commercial

ESCAPING GRAVITY: *My Quest to Transform NASA and Launch a New Space Age*

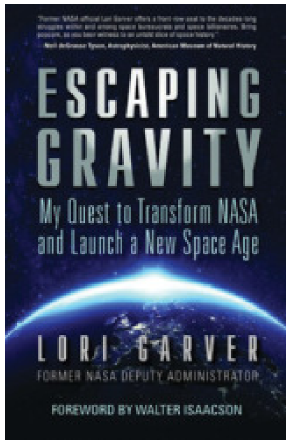
Lori Garver
Diversion Books, 2022
304 pages, ISBN 978-1635767704
US$28.99, hardcover

FOR THE U.S. SPACE PROGRAM during the past decade, crisis and opportunity have gone hand in hand. We've seen the end of the Space Shuttle era, which had its last flight in 2011, and the rise of companies such as SpaceX taking astronauts to the International Space Station (ISS). These evolutionary changes have occurred alongside the promise (and controversy) surrounding the Space Launch System (SLS) rocket and the Artemis initiative to return to the Moon.

Lori Garver's book grew out of this uncertain yet propitious period. Deputy administrator at NASA from 2009 to 2013, Garver chronicles her unrelenting push during this time to convince agency bureaucrats to begin working with commercial rockets. Her fierce advocacy often put her at odds with the space agency's male-dominated, corporate culture. She found herself fighting against entrenched political interests and the agency's old-school status quo. It was a tough row to hoe, but Garver and her like-minded colleagues persevered, ultimately transforming the way NASA does business.

> We're in for a fascinating stretch, with the recent successful Artemis I mission heralding the return of humans to the Moon.

The book offers a ruthlessly honest insider's view of the discussions and debates that raged behind the scenes. Garver describes the cycle of government contracts and cost overruns as a giant "self-licking ice cream cone," one that virtually eliminated the one method that has long proven itself effective in driving innovation, efficiency, and cost-cutting: competition. She also details the indecisive path through several presidential administrations to settle on an objective for SLS and Artemis — from going to the Moon, to an asteroid, to Mars, then back to the Moon again. Garver was also on hand for the James Webb Space Telescope's rocky path through Congress (it was almost canceled in 2011), which ultimately led to its successful launch on Christmas Day, 2021.



But Garver's greatest achievement as NASA's second-in-command was undoubtedly her success — with the support of what she calls "space pirates" seeking to transform modern spaceflight — to get NASA to tap the private sector to deliver cargo and eventually crew to the ISS. This took place after the end of the Shuttle era, when NASA found itself paying for seats on the Russian Soyuz spacecraft, a situation that became more precarious after Russia's annexation of Crimea in 2014.

Garver recounts how NASA finally brought startup SpaceX into the fold, albeit with caution. Originally, she notes, the agency didn't want its iconic logo on SpaceX's Falcon 9 rocket. Fast-forward to today, and a new version of NASA's familiar worm logo adorns SpaceX rockets carrying astronauts to the ISS (along with Tesla roadsters delivering them to the launch pad).

"The space pirates saw early that the biggest obstacle to space development was the lack of affordable, reliable access to space," Garver writes in *Escaping Gravity*. "They believed the Space Shuttle was impeding progress and to some this made the space pirates heroes and to others villains."

In the end, the savings to taxpayers has been huge. Today, as Walter Isaacson notes in the book's Foreword, SpaceX transports astronauts to the ISS "at a cost an order of magnitude lower than all previous human spaceflight missions."

While Garver's indictments of NASA culture during her time as the agency's deputy administrator can be scathing, she also optimistically chronicles the push to get NASA out of the role of taxi service to low-Earth orbit and back to deep-space exploration with robots. Such missions have blossomed over the past decade — we've seen two rovers land on Mars, New Horizons fly past Pluto, and Juno arrive at Jupiter.

Read *Escaping Gravity* for a unique, brutally honest perspective on NASA in a time of transition, and for a glimpse of the decade of space exploration to come. One thing is certain: We're in for a fascinating stretch, with the recent successful Artemis I mission heralding the return of humans to the Moon sometime in the coming years.

■ **DAVE DICKINSON** posts biweekly on **skyandtelescope.org**, focusing on spaceflight with an astronomy angle.

How Do I Dim the Moon in My Scope?

WHO DOESN'T LOVE looking at the Moon? For many night-sky enthusiasts — myself included — Earth's nearest celestial neighbor was the very first thing we trained our brand-new telescope at. It's irresistibly big, bright, and beautiful. But for some, there might be a bit too much of that second "b" (bright). At times, the Moon's sunlit face can be overwhelmingly luminous. Is there any way to dim it down a notch? Thankfully, the answer is yes!

Let's begin by noting that, though the Moon can indeed *seem* "blindingly bright," it won't actually harm your eyes no matter how long you stare at it. (The Sun is the only celestial target with the potential to do serious damage to your vision — *always* use a safe solar filter when viewing it.) In reality, the lunar surface is actually quite dark and only

▲ **MOONLIGHT, MOON BRIGHT** Proving one really can have too much of a good thing, the lunar surface can appear uncomfortably bright in even a modest telescope. Thankfully, there are a number of simple strategies to limit the illumination.

GARY SERONIK

▲ **POLARIZING POWER** A variable-polarizer eyepiece filter consists of two halves (shown separated in the photo above) that allow the user to adjust the brightness of the telescopic image over a wide range. As a bonus, the two parts of the filter can be separated and used as a conventional polarizer filter for daytime viewing of the first- or last-quarter Moon.

▲ **LUNAR GOODIE** Dedicated Moon filters like the one shown here are a quick and easy way to dim the telescopic view of the lunar surface. Also known as neutral-density filters, they're available in several different strengths. Using such a filter couldn't be easier. Simply thread it into the barrel of your eyepiece and enjoy the view.

reflects about 12% of the light hitting it — about the same as an asphalt road. So why is it so dazzling? Simply because you're usually looking at it at night, when it's surrounded by a dark sky and your eyes likely have become at least partially sensitized to the nighttime environment through a process known as *dark adaptation*. When you train your scope at the Moon, your poor observing eye gets blasted with more photons than it's ready for. You might even experience a disorienting lunar afterimage when you look away. So, even if the view isn't harmful, you may well find it uncomfortable. Thankfully, taming lunar illumination is pretty easy.

The first thing to try is boosting your scope's magnification. This has the effect of spreading out the Moon's light, making it appear less brilliant. How much power do you need for this to work? The more you apply, the dimmer (and larger) the Moon appears. The obvious advantage of this approach is that you don't have to buy anything extra — you probably already have the necessary eyepieces. You don't want to go too far down this road, though. If the image starts looking blurry due to excessive magnification, it's time to back off a bit.

But what if the view is still too bright for your tastes, or you want to see the entire lunar disk but just more dimly? This is where filters are your friend. You can purchase a range of specialized filters that screw into the base of your eyepiece — there's even one called a "Moon filter," and its only job is to dim the view. Sometimes also referred to as "neutral density filters," they can be purchased in a couple of different strengths, or *transmission values* (expressed as a percentage of the light allowed through). Just be sure to pick a model that matches the barrel diameter of the eyepiece(s) you plan to use — typically either 2-inch or 1¼-inch. Expect to spend $12 to $25 for one.

A more versatile option is a *variable polarizing* filter. The advantage to this filter is that you can dial in a wide range of transmission values. In effect, a variable polarizer works like a dimmer control for the Moon, allowing you to fine-tune its brightness to precisely match your preference. Such filters also allow you to make the Moon much dimmer than any conventional fixed filter can. A variable polarizer is essentially a pair of polarizers that rotate with respect to each other to achieve the dimming effect. And because you are in effect buying two filters, it tends to be more expensive than a regular Moon filter. Typically, a variable polarizer costs in the range of $25-$30 for 1¼-inch models.

What I like about this solution is that you can usually unscrew one of the filter elements and use it as a regular polarizer. Such a filter offers surprisingly good daylight views of the Moon, when it's near first- or last-quarter phase. Used this way, the polarizer doesn't dim the image, rather it renders the daytime sky an appealing dark blue, thus improving contrast.

For the sake of completeness, I'll also mention *planetary filters*. These are colored filters designed to enhance the contrast of surface features on planets (principally Mars and Jupiter). Since the Moon is essentially gray, there's minimal color contrast to work with. Instead, these devices render the lunar surface a specific color. (The green one is handy if your goal is to convince someone that the Moon really is made of green cheese.) Planetary filters do cut down lunar luminance, but unless you want a fake blue Moon (or a red, orange, yellow, or green one), the options already mentioned are better. Of course, if you have some planetary filters already, there's no harm in trying one out to see if you like it.

Although this discussion has focused on improving your observing comfort, you'll also see more detail when your eye isn't being overwhelmed with photons. Indeed, the finest view I ever got of ol' Luna was through a friend's homebuilt 16-inch reflector telescope. He'd just completed figuring the mirror but hadn't yet sent it out to have its reflective coating applied. Eager to test this new optic, we aimed his new scope at the Moon. And what a view it was! The lunar surface was rendered with the full (and impressive) resolution of a 16-inch aperture, but thanks to the bare glass, it was only as bright as it would have appeared in a 3-inch telescope. It was an astonishing sight — richly detailed but wonderfully comfortable.

Mind you, for a true lunaphile, bright or dim, the Moon is *always* an astonishing sight. ■

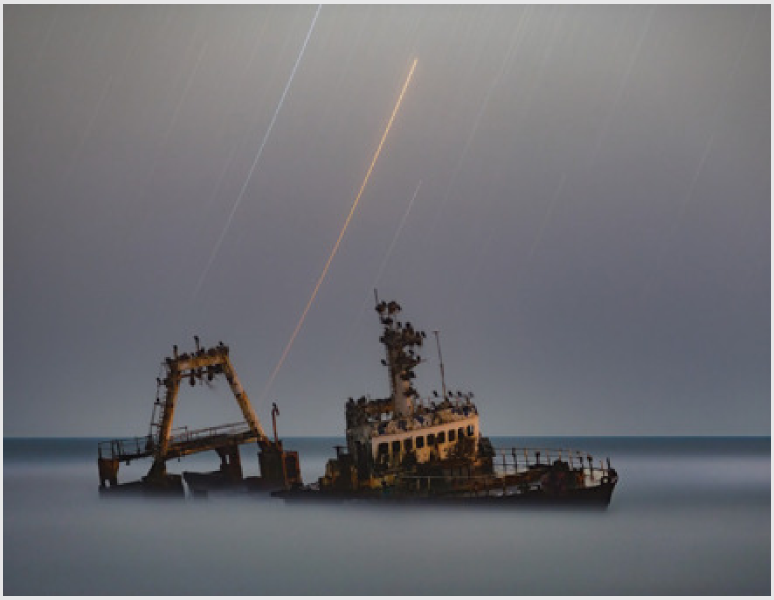
POLARIZER: GARY SERONIK; MOON FILTER: CELESTRON

HORSING AROUND IN THE SKY

Vikas Chander

Barnard 33, popularly known as the Horsehead Nebula, is a thick cloud of gas and dust that towers in front of the reddish emission nebula IC 434. Bluish reflection nebula NGC 2023 is visible at bottom left. North is to the left.

DETAILS: *PlaneWave CDK17 Corrected Dall-Kirkham telescope and SBIG STXL-11002 camera. Total exposure: 25½ hours through LRGB and Hα filters.*



◁ SKELETON COAST

Vikas Chander

Reddish Antares in Scorpius dims as it sets behind the decaying remains of the *Zella*, a fishing trawler scuttled in the shallow waters of Skeleton Coast National Park in Namibia.

DETAILS: *Nikon D850 camera with ZEISS Milvus 135-mm lens. Total exposure: 30 minutes at ISO 200, f/2.8.*

▽ GALACTIC PERSPECTIVE

Bob Fera and Eric Coles

At around 50 million light-years away, spiral galaxy NGC 7331 appears to dwarf other galaxies in the field that are roughly eight times more distant.

DETAILS: *PlaneWave CDK20 Corrected Dall-Kirkham telescope and QHY600M camera. Total exposure: 12 hours through LRGB filters.*

MARS MEETS THE MOON

Richard H. Sanderson

Mars appears to hover just beyond the edge of the Moon as seen from Feeding Hills, Massachusetts, on the evening of December 7, 2022. Tycho Crater stands out boldly on the Moon, while the barest hint of Mars's dark Mare Cimmerium can be seen on the Red Planet.

DETAILS: *Homemade 8-inch Dobsonian with iPhone 12 camera. Total exposure: $^{1}/_{1416}$ second at f/1.6.*

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△ NEBULOSITY IN MONOCEROS

Antoine and Dalia Grelin

Open cluster NGC 2264 at center, often referred to as the Christmas Tree Cluster, is surrounded by diffuse nebulosity that bears the same designation. The comet-like object to its lower right is NGC 2261, Hubble's Variable Nebula.

DETAILS: *Askar FRA500 astrograph and QHY600C camera. Total exposure: 33 hours through a dual-bandpass filter.*

▽ DOLPHIN NEBULA

Dan Llewellyn

Fast stellar winds from Wolf-Rayet star EZ Canis Majoris have produced the large bubble of nebulosity known as Sharpless 2-308 seen at right. North is to the left.

DETAILS: *Askar FRA600 108-mm astrograph and Sony α7III camera. Total exposure: 1.26 hours through OPT Triad filters.*

▽▽ BOB-TAILED COMET

Chris Schur

Comet ZTF (C/2022 E3) is seen drifting across Corona Borealis on December 26, 2022, with its short, broad dust tail and long, faint ion tail.

DETAILS: *Orion 10-inch Newtonian astrograph and ZWO ASI071MC Pro CMOS camera. Total exposure: 90 minutes.*

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An Astronomer's Life in Wartime

Twice in a decade, the author has had to flee his home and start a new life elsewhere.

I LIVE IN UKRAINE and have been fond of astronomy since childhood. Until 2014, I lived in Donetsk, in eastern Ukraine, where I built a house with an optical and radio observatory on the roof. I was very happy to spend time there alone with space. At the observatory, I worked on new projects for astronomy enthusiasts during the day and tested them under the dome at night.

But in 2014, Russian troops and mercenaries attacked the Donetsk and Luhansk regions of Ukraine and annexed Crimea. After that, my life changed dramatically. Instead of observing the stars, in May 2014 I used my rooftop telescope to view the battle for Donetsk's Sergei Prokofiev International Airport, which lay just across the river from my house. In the eyepiece, I watched as a shell struck a tank, exploding it and tearing the turret off.

Later in 2014, Russian troops bombed my house and observatory, forcing my family and me to move to then-peaceful Kharkiv in the northeast. I founded Astro-Gadget there in 2016. Inspired by John Dobson and his concept of popularizing astronomy, my company produces affordable gear for enthusiasts. Programmers, designers, and engineers from around Ukraine help develop our products.

Early in 2022, even though Russia had massed troops near our border, I didn't believe it would invade. I thought Vladimir Putin wouldn't want to destroy his own economy, lose access to Western markets, and impoverish his own people by plunging his country into war. But as the world knows, Russian troops invaded Ukraine on February 24, 2022, with massive bombing and rocket attacks on our cities.

I was in Kharkiv and saw it all. On March 1, I watched a Russian cruise missile fly over us and, seconds later, I heard an enormous explosion. I was evacuating our office at the time, and my path led through Kharkiv's Freedom Square. Later I saw that the rocket had destroyed the regional administration building and severely damaged the square itself.

In the first days of the invasion, Kharkiv was heavily bombed, houses burned all around, and people were dying. We spent the first days in a bomb shelter, aiding victims during pauses in the shelling. I had recently bought a house in Kharkiv and had dreamed of building a new observatory. But I soon realized that, because of Russia's cruel, aggressive actions, my new home and dreams would be lost a second time.

About a week after the invasion began, we managed to evacuate to Khmelnytskyi in western Ukraine. Here we continued to help victims and began to restore the company's activities. All members of our team relocated to Ukrainian cities closer to the border with the European Union, though many of our friends have gone abroad.

I would like to return to my home and company in Kharkiv. But currently it's too dangerous to live and work in the city, which lies just 30 kilometers (18 miles) from the Russian border. So I will remain in Khmelnytskyi. But we do not lose heart, and thanks to the love for astronomy and the support of astronomers around the world, we continue to do our work and lead our lives.

■ **ALEXANDER PLAKHA** has worked as an engineer and electronics developer at various Ukrainian institutes. He owns Astro-Gadget, **astro-gadget.net**.

▲ Alexander Plakha (top, with his telescope) fled his Kharkiv home and observatory (above left) soon after a Russian missile destroyed the city's Freedom Square on March 1, 2022 (bottom right). Eight years earlier, on May 26, 2014, Plakha observed the battle for the Donetsk airport (top right).

ALL PHOTOS COURTESY OF ALEXANDER PLAKHA

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